Proceedings of the Workshop on

IRRIGATION AND VECTOR-BORNE DISEASE TRANSMISSION

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JOINT WHO/FAO/UNEP PANEL OF EXPERTS
ON ENVIRONMENTAL MANAGEMENT FOR VECTOR CONTROL

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

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December 1986
INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
SRI LANKA

Citation: ***IIMI pub 86-02***

International Irrigation Management Institute (IIMI) and the Joint WHO/FAO/UNEP Panel of Experts on Environmental Management and Vector Control (PEEM). 1986. Proceedings of the Workshop on Irrigation and Vector-Borne Disease Transmission. Digana Village, Sri Lanka: IIMI Pub.

/disease vectors/irrigation management/environmental control/ /developing countries/health/malaria/filariasis /Mahaweli project

DDC 631.7.5

Summary: Vector-borne diseases continue to be one of the predominant public health problems in Sri Lanka and other developing countries. Diseases such as malaria and filariasis pose an undeniable threat to the success of water resource development, and the role of preventive or mitigating measures is discussed as a priority in the planning, implementation, and management of irrigation projects.

Please direct inquiries and comments to the:

Communication and Publication Office
INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
Digana Village via Kandy, Sri Lanka

Tel. 74274, 74334, 74251; Tlx. 22318 IIMI HQ CE

PRINTED AT KANDY OFFSET PRINTERS LTD

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Joint WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control

The WHO/FAO/UNEP Panel of experts on Environmental Management for Vector Control (PEEM) was established in 1981 according to the Arrangements agreed upon by the three participating organizations.

The objective of PEEM is to create an institutional framework for effective interagency and intersectoral collaboration by bringing together various organizations and institutions involved in health, water and land development and the protection of the environment, with a view to promoting the extended use of environmental management measures for vector control in health programmes and in development projects as health and environmental safeguards.

International Irrigation Management Institute

The International Irrigation Management Institute (IIMI) is an autonomous, non-profit international organization chartered in Sri Lanka in 1984 to conduct research, provide opportunities for professional development, and communicate information about irrigation management. Through collaboration, IIMI seeks ways to strengthen independent national capacity to improve the management and performance of irrigation systems in developing countries.

IIMI's research program aims at deriving methodologies and conceptual understandings that result in better management of irrigation resources. The training program is designed to strengthen leadership and management skills among professionals responsible for planning and managing irrigation systems. The information program supports IIMI researchers and an international network of people interested in irrigation management by providing publication, library, and documentation services.

IIMI's headquarters is in Digana Village near Kandy, about 130 km east of Colombo and central to some of Sri Lanka's extensive irrigation projects.

Preface

Throughout the long history of Sri Lanka irrigation has been of vital importance. In ancient days, it formed the basis on which the Sinhalese culture flourished. The extensive network of canals and reservoirs, constructed by the kings of Anuradhapura and Polonnaruwa brought prosperity to their people. Yet the irrigation works were also a vulnerable target in time of war, and their destruction led more than once to acute crisis with famine and disease, and finally to a general decline.

The role of malaria epidemics in this decline is disputable. It is not clear at which moment in time malaria reached the island. Nor is it known to what extent the engineers who served the ancient rulers were aware of the relation between certain environmental conditions and the prevalence of the disease. It would seem that their engineering practices were "environmentally sound," as it would be called nowadays, and did not create major adverse health effects.

In modern times, the people of Sri Lanka face the challenge of bringing the areas of the dry zone, so notoriously malarious, under cultivation again. The country needs to feed a growing population. Lacking fossil fuels, it has to resort to hydropower to generate sufficient energy. And its economy has to expand to create better employment conditions.

Efforts over the past decade include the reservoir and resettlement projects of Inginimitiya, Kirindi Oya, Muthukandiya, and Mahadivulwewa. They also include flood protection schemes and village irrigation rehabilitation projects. But the national and international focus is of course on the Accelerated Mahaweli Project.

Vector-borne diseases continue to be one of the predominant public health problems in Sri Lanka. Measured by morbity and mortality, malaria certainly is the most important. Others, including filariasis and Japanese encephalitis, contribute their share to ill health. Vector-borne diseases pose an undeniable threat to the success of water resource development, and the consideration of possible preventive or mitigating measures remains a priority item in the planning and implementation of irrigation and other water projects.

Since 1981 the WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM) has been promoting the use of environmental management measures as a contribution to sustainable economic development. Improved water management is a key component of such an approach. Research in the field of water management is also a priority issue in the mandate of the International Irrigation Management Institute (IIMI), with the objective to obtain methodologies to secure a maximum agricultural yield with a given amount of water.

The ultimate objectives may differ, but the concrete research questions to be solved show great overlap. If improvement of water management techniques, from an agricultural point of view, leads to adverse health implications, it will in the end fail to contribute to the intended improvement of the quality of life. Considering the above, it was decided to organize a workshop on irrigation and vector-borne disease transmission, to stimulate a dialogue between the irrigation, health and environment sectors in Sri Lanka and to explore whether a basis could be found for further collaboration between PEEM and IIMI. The organizers believe the workshop reached both goals. They hope that these proceedings will contribute to a continued dialogue in Sri Lanka, and they envisage promising opportunities for the future PEEM/IIMI collaboration.

These proceedings of the workshop on irrigation and vector-borne disease transmission, which was held at the International Irrigation Management Institute (IIMI) in October 1985, were prepared by IIMI and are a joint publication of IIMI and PEEM. The workshop stimulated a dialogue between the various sectors in Sri Lanka involved in irrigation development, health and the environment, and this publication aims at further promoting intersectoral collaboration in this field.

The organizers wish to acknowledge and thank the editors: Mrs. Verla Selleck and Mrs. Regina Z. Cowell, IIMI, Sri Lanka. Dr. R. J. Tonn, Chief, Planning, Management and Operations, WHO, Geneva; Mr. T. H. Mather, Chief, Water Resources, Development and Management Services, FAO, Rome; and Mr. A. Kandiah, Technical Officer, Water Resources, Development and Management Services, FAO, Rome provided help in technical editing. Mrs. Shanthi Dissanayake, IIMI, provided editorial assistance, and Ms. Shanthi Weerasekera and Ms. Ameeta Perera, IIMI, provided workshop and typing assistance.

Dr. Robert Bos, PEEM Secretariat, Workshop Coordinator
Dr. Leslie E. Small, IIMI, Workshop Coordinator
Dr. Robert Cowell, IIMI, Proceedings Editor

Sri Lanka, October 1986

Executive Summary Workshop on Irrigation and Vector-Borne Disease Transmission

Robert Bos[1]

Like so many other Third World countries where transmission of vector-borne diseases occurs, Sri Lanka is presently facing a crisis in its vector control programme which may have severe consequences if it is not properly dealt with. The nature of the problem is four-fold. The discovery of malathion resistance in the principal vector of malaria, *Anopheles culicifacies,* marks the beginning of a decreasing effectiveness of residual spraying with this insecticide. Simultaneously, chloroquine resistant *Plasmodium falciparum* strains will undermine drug treatment strategies and gradually diminish their impact. A third phenomenon jeopardizing the current vector control programmes is the rapid decline in public acceptance of malathion spraying. The negative effect this has on the control programme's performance is further enhanced by public action after spraying, such as white washing of recently sprayed walls. And finally, the economic reality of the current decade affects both the possibility to purchase insecticides as well as the operational potential of national vector control programmes.

In Sri Lanka, the above problems should be considered against the background of a highly varied ecology with a diversified mosquito fauna, which includes many potential and confirmed disease vectors. The effect of man-made environmental changes on the ecology of vector species has always been important, reliant as the country is on irrigated rice cultivation. However,the extensive environmental changes occurring under the Accelerated Mahaweli Project, with major water resource development going on in what is traditionally the most important malarious area of the country, are unprecedented. They are the result of a necessary development to ensure food production, power generation and employment for future generations. But, if no adequate precautions are taken, they also carry the risk of increased ill-health and its negative impact on overall human development.

Under these circumstances, the development of sound strategies for disease control must be based on, amongst other things, research concerning the possible effects of irrigation development on the ecology and behaviour of disease vectors. Generally three categories of vector-borne diseases may be distinguished in this context: 1) those directly connected to irrigation development, for instance, malaria and Japanese encephalitis; 2) those resulting from resettlement and urbanization accompanying irrigation development, for instance, dengue and lymphatic filariasis; and, 3) zoonotic diseases man comes in contact with during jungle clearance, for instance, chickungunya.

Present Status of Research on Vectors and the Diseases they Transmit

Studies on vector population dynamics in parts of Mahaweli System C where irrigation development has not yet taken place, indicate a high level of mosquito species diversity. Many species with the potential to become important vectors once a human disease reservoir has been established have been identified. These include *Anopheles culicifacies, A. varuna, Mansonia annulifera, Aedes albopictus, Culex tritaeniorhynchus and C. quinquefasciatus.* A simple forecast, considering the environmental changes and comparing with other locations where water resource development has taken place under similar conditions, suggests that *Anopheles culicifacies* will become the predominant species after development, with all the implications this may have for health.

Epidemiological studies in the part of Mahaweli system C already under development show that

[1] PEEM Secretariat, Geneva, Switzerland.

among resident and resettled populations both *vivax* and *falciparum* malaria are prevalent and that active transmission takes place. There is also evidence of active Japanese encephalitis virus, and a definite risk of spreading filariasis to this area exists. Additional entomological studies show the presence of vector species of the three categories of diseases mentioned above. Results of studies in other parts of Sri Lanka indicate that paddy fields are a major breeding place for anopheline mosquitoes, while irrigation and drainage canals contribute relatively little in this respect.

Under conditions in which the lack of human resources and equipment form major constraints, and all professional groups have to deal with heavy workloads, the merits of a better distribution of the research tasks over the several groups needs to be considered. Further studies on the effectiveness of environmental management for vector control, including studies on the role of proper water management, should be of pilot nature, aimed at promoting an integrated vector control approach with environmental management as its basic component.

For future research, a fair balance must be found between obtaining detailed knowledge and what can be practically done in a fairly large-sized country with many different local conditions. It is clear that an impressive amount of data has been collected on vector bionomics, ecology, and the role of several species in disease transmission. There is a need to properly analyse these data, prepare an inventory of the present knowledge, and make the information available to planners and decision makers in the health and water resource development sector. This action will help ensure adequate mitigation of vector-borne disease hazards.

Intersectoral Collaboration

At present several intersectoral linkages regulate health care in the areas where water resources are under development. Although preventive and curative services are both part of the health programme, preventive services tend to be restricted to immunization and prophylactic drug treatment, and insufficient attention is given to the incorporation of health safeguards, such as environmental management measures, into irrigation projects. Recommendations to improve the situation include upgrading the technical subcommittee of the Mahaweli Economic Agency (MEA), giving the present ad-hoc coordination between the Mahaweli Economic Project and the national vector control organizations a formal basis, and earlier involvement (from the planning stage onwards) of the Ministry of Health in new developments.

Environmental Management for Vector Control

Five criteria for the application of environmental management for vector control are reiterated: 1) the measures must be known to be effective against the target vector; 2) they must be socially acceptable; 3) they must be cost-effective compared to other feasible methods; 4) they must be economically sustainable by the local community, and 5) they must be compatible with local agricultural practices.

In relation to environmental management some new elements are introduced, and relevant research needs are emphasized. The socio-economic aspects of irrigation-associated health problems are raised, with considerations on the loss of labour due to the prevalence of vector-borne diseases. Adequate indicators must be developed to cope with this. Also educational approaches need to be developed which fit into the training programmes on strictly agricultural issues as they already exist for farmers. Ideally, there should be a two-way information flow so that valuable traditional knowledge of the farmers can be collected and recorded.

The results of a recent field survey on the engineering aspects of irrigation development in relation to vector breeding, carried out under the auspices of the International Institute for Land Reclamation and Improvement in Mahaweli System C, bring to light some salient issues. In this survey a matrix approach has been applied, linking potential breeding places with specific disease vectors, the location of these breeding places with the phase in the irrigation cycle, and the occurrence of these breeding places with water management practices. A number of characteristics of the schemes in System C have been pinpointed as being of direct relevance to vector production. First and foremost is the discrepancy between the calculated need of water and the actual intake. Clearly, the level of excess water in the system gives rise to collection of water in depressions, thus creating suitable breeding places. Of the other factors considered important in vector propagation, the lay-out of tertiary canals, improper land levelling, and disruption of the natural drainage system all relate to the subject of water management. More than anything else, this survey demonstrates the need for further in-depth studies to better define the links between proper water management and vector breeding.

Research on Water Management for Vector Control

As for the developments in irrigated agriculture itself, a shift in approach can be observed from expansion of the cultivated area to methods of increasing the intensity with which the existing agricultural potential is used. Irrigation is considered a key link in the chain of technical developments leading to increased production. The International Irrigation Management Institute (IIMI) has been created as an international research organization with the objective to enhance national capacities to improve the management and performance of irrigation systems.

For IIMI's research programme, three general areas of investigation have been recognized: systems management, rehabilitation and design for management, and small-scale irrigation. In each area institutional/ social, physical, biological, information and financial issues will be considered. From the point of view of IIMI, the prevention and control of irrigation-associated vector-borne diseases comes under the biological issues. Critical questions which IIMI should address in this context concern the cost-effectiveness of environmental management, the nature of the cause-and-effect relationship between irrigation development and vector-borne disease prevalence, and the research needs for the development of alternative management techniques. A valid distinction can be made between irrigation in humid and semi-humid areas where rice is the predominant crop, and irrigation in relatively arid areas, where crops other than rice predominate.

From the point of view of the WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM), a broad focus on the relation between irrigation and health is required, not limited to disease vector ecology but also including matters of epidemiology. In the past, numerous studies have been carried out on the health impacts of large dams, but far fewer on those of small dams, and even less on irrigation systems. Studies on the epidemiology of vector-borne diseases in irrigation schemes in a steady state will lead to more specific studies on entomological and malacological parameters and on the effectiveness of alternative irrigation management strategies. Environmental management for vector control and irrigation management for increased agricultural production have common denominators. Their coordinated implementation is likely to lead to mutual reinforcement of the effectiveness in attaining their goals.

Conclusion

The facts and arguments presented at the workshop indicate that there is a considerable and sound basis for collaboration between PEEM and IIMI, in the promotion and execution of research which will contribute to the improvement of health of those who inhabit irrigation schemes, and who make them function. Three approaches should be considered: 1) studies on possible improvements in the design and construction of irrigation schemes, 2) studies on improved operation of irrigation schemes, and 3) studies on suitable methods for the rehabilitation of irrigation schemes. In each of these three approaches improvement of health and agricultural production should go hand in hand in order to coordinate the goals of PEEM and IIMI into an effective policy.

The Present Malaria Situation in Sri Lanka with Particular Reference to Areas where Irrigation has Recently been Introduced

M. U. L. P. Samarasinghe[1]

How long malaria has existed in Sri Lanka is a matter of conjecture. However, there is ample evidence that the disease has been prevalent in the island for centuries. Plancius' map of 1592 stated that the Kingdom of Yala in the southeastern part of the island was deserted and depopulated by fever sickness for over 300 years. Knox, in a 1681 account of his captivity, refers to incidence of high fever in areas north of Kandy. Father Queroz, in 1687, alludes to the ancient court of Anuradhapura as being abandoned on account of protracted pestilence. Frequent references are made of fever sickness during the Dutch and British periods.

Epidemics

Sri Lanka has suffered from several epidemics of malaria of varying degrees of severity and distribution. These have occurred regularly every four to six years. Epidemics have occurred in 1906, 1914, 1919, 1923, 1928-29, 1934-35, 1939-40, 1945-46, and 1967-69. The most devastating epidemic occurred when 1.5 million people contracted the disease between October 1934 and April 1935, and about 80,000 died. The entire Western and Sabaragamuwa Provinces, lower parts of the North Western, and the greater portion of Kandy and Matale Districts were affected.

Factors Affecting the Epidemiology of Malaria in Sri Lanka

Sri Lanka is an island in the Indian Ocean close to the southern extremity of India. Measuring 435 kilometers from north to south, and 225 kilometers across at the widest part, it has a total surface area of 65,863 square kilometers. The south-central portion is mountainous; above an altitude of 914 meters malaria transmission does not occur. The island is has many rivers which radiate from the central hills. Malaria outbreaks are mostly associated with rivers flowing through the western and southwestern areas.

The climate is tropical with little seasonal variation in temperature and humidity. In the flat coastal plains the temperature ranges between 26-29°C. However, there is considerable temperature difference between the lowlands and the hill country. The relative humidity is high: an average day-time humidity in the coastal plains of 70%, and of 60% or more in the interior, while night-time humidity is over 80%. The temperature and humidity conditions which prevail in the flat, coastal plains and foothills favor perennial transmission of malaria.

Rainfall is the most important climatic factor influencing the transmission and distribution of malaria in Sri Lanka. The rainfall is associated with the two monsoons, the southwest monsoon which prevails from May to September, and the northeast monsoon from November to March.

Therefore, the division of Sri Lanka into three climatic zones based on rainfall patterns is very relevant to the epidemiology of malaria (Figure 1). A distinction is made between the dry zone (less than 51 centimeters), the intermediate zone (51-102 centimeters), and the wet zone (more than 102 centimeters). The endemicity of malaria in the dry zone varies from high meso to hyperendemic with

[1] Acting Director, Anti-Malaria Campaign, Sri Lanka.

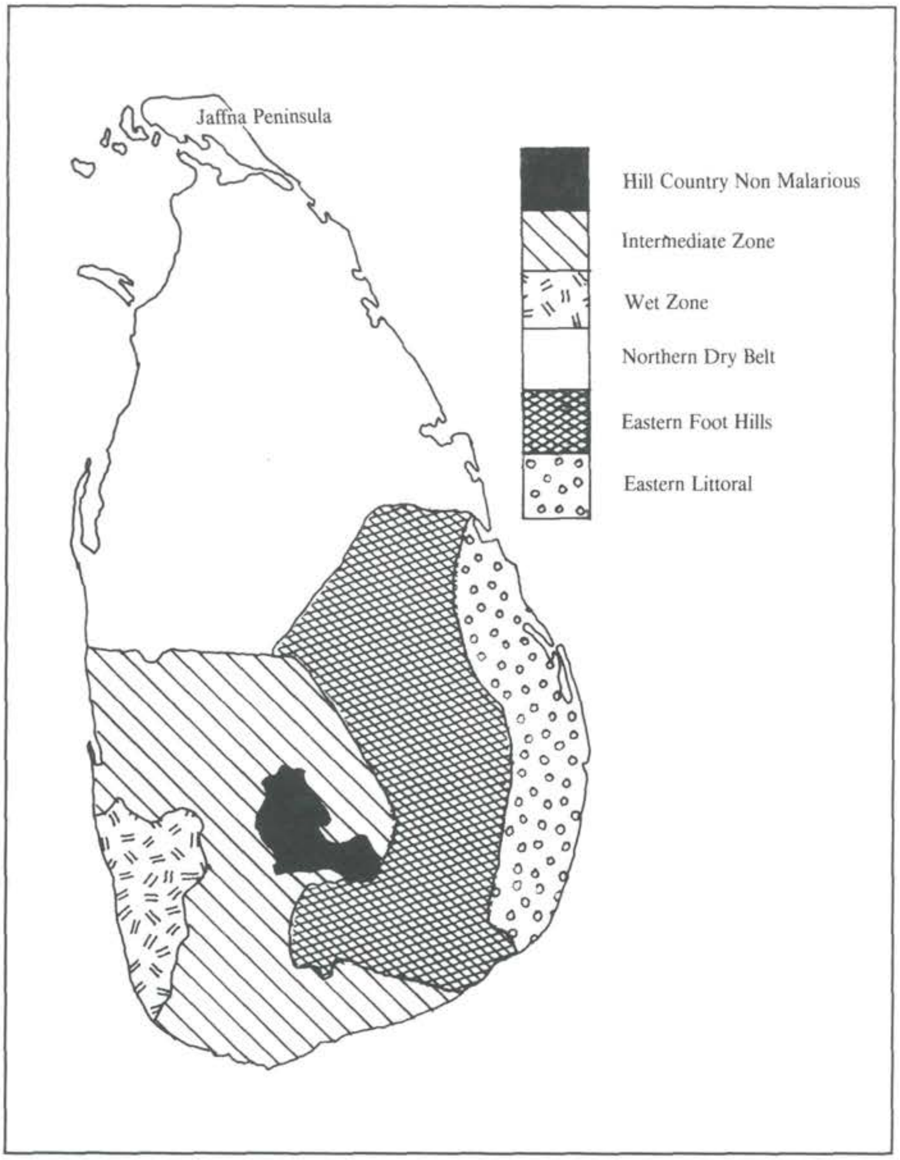


Figure 1.
Malaria Epidemiological zones.

pockets of holoendemicity in the intermediate zone from low to high mesoendemic, while the wet zone is non-malarious or hypoendemic.

Epidemic outbreaks in the wet and intermediate zones are favored by deficient rainfall which leads to the drying up of rivers and streams and the formation in the riverbeds of numerous pools suitable for breeding *Anopheles culicifacies,* the vector of malaria in Sri Lanka. On the other hand, excessive rainfall in the dry zone results in the formation of large numbers of surface pools which also foster an increased incidence of malaria.

Parasite Species

The prevalence of parasites has shown considerable variation by season, year, and zone. *Plasmodium malariae* was the predominant species in the endemic zone and, in non-epidemic years, in the intermediate and wet zones. *P. vivax* and *P. falciparum* predo-minate during seasonal peaks in the endemic zone and during epidemics in the intermediate and wet zones.

The use of residual insecticides resulted in a change in the parasite picture. *P. malariae* has faded away and the commonly encountered species have been *P. vivax* and *P. falciparum* with P. vivax in the ascendant. Only with the cessation of spray operations in 1964, did *P. malariae* temporarily reappear as the predominant species from 1964 to 1966.

Since the 1967-69 epidemic, *P. vivax* has been the predominant species in over 95% of infections. After 1975, there have been occasional peaks in the relative number of *P. falciparum* cases of over 5%. *P. malariae* has virtually disappeared.

Vectors of Malaria

Twenty-two Anopheline species have been recorded in Sri Lanka, but only *A. culicifacies* has been incriminated as the vector of malaria. It was the only proven vector in the country until recently, when P. R. J. Herath and co-workers demonstrated the development of a sporogonic cycle of *P. vivax* in several other Anophelines, many of which are malaria vectors in other countries. However, *A. culicifacies* remains the major vector. This species is essentially a dry zone mosquito found in jungle-covered plains and villages. Its incidence diminishes with altitude, becoming scarce above 609 meters, and rare above 762 meters. The nature of the aquatic environment it breeds in may vary, but it prefers clear, sunlit, fresh waters. Intense breeding of *A. culicifacies* occurs in sand and rock pools of drying rivers, and in the margins of slow moving waterways such as streams and irrigation channels. Although its vectorial capacity is generally considered weak, resulting in unstable malaria transmission, in Sri Lanka this species has a greater longevity and a higher human blood index than elsewhere. Malaria transmission in the wet zone is of a more stable type. The annual incidence of malaria for Sri Lanka during the past 10 years is shown in Table 1.

Malaria and Irrigation

The epidemiology of malaria is not only influenced by natural factors, but also by human activities such as irrigation. In Sri Lanka, large water resource development projects such as Minneriya, Gal Oya, and, more recently, the Mahaweli Project, have increased the malariogenic potential of areas through increased vector propagation, aggregation of labor, and resettlement of people from non-malarious areas who may have little or no immunity. The resulting outbreaks of malaria have been a setback to project implementation (Table 2).

Water resource development projects and the expansion of irrigation systems create favorable conditions for malaria transmission. Wild animals disappear as vast tracts of forest are cleared. *A. culicifacies,* which is usually a zoophilic species having a preference for cattle blood, is forced to turn to man for its blood meals, leading to an increased man-vector contact. The vast network of irrigation channels, if not properly maintained, will

Table 1. The annual malaria incidence in Sri Lanka for 1975-85.

YEAR	EXD	POS	PV	PF	PM	MIX	ABER	API
1975	1492008	400777	336924	62071	-	1782	9.9	21.75
1976	1408644	304487	285696	18205	-	586	10.82	9.0
1977	954756	262460	251726	10431	-	303	6.81	8.7
1978	968327	69685	67809	1826	-	50	6.7	4.87
1979	1001217	48004	46636	1313	-	55	6.8	3.30
1980	803692	47951	46476	1423	-	52	5.4	3.27
1981	892143	47383	46143	1211	-	29	6.1	3.17
1982	1127575	38566	36967	1541	-	58	7.5	2.55
1983	1055626	127264	122764	4341	-	159	6.9	7.99
1984	859178	149470	145711	3593	01	165	5.5	9.52
1985	686565[a]	62624	58437	3988	-	199		
TOTAL	1249731	1558671	1445289	10994	01	3438		

[a]Jan - Aug

Table 2. The annual incidence of malaria for the period 1982-85 in the Mahaweli Project, Systems H, C, and B.

	SYSTEM H				SYSTEM C				SYSTEM B			
	CD & MH Tambuttegama PU Nochchiyagama PU Talawa PU Galnewa				PU Girandurukotte RH Lihiniyagama DH Mahiyangana DH Medagama				PU Aralaganwila DH Hingurakgoda			
	1982	1983	1984	1985	1982	1983	1984	1985	1982	1983	1984	1985
EXP	8181	6183	7206	5217	7642	7206	7107	7821	8147	6714	10201	4882
POS	353	1281	2988	1217	1189	1675	1598	2045	329	798	1701	952
PV	344	1239	2966	1185	1138	1632	1577	1524	311	765	1645	864
PF	8	42	21	32	51	42	20	484	18	31	51	85
PM	-	-	-	-	-	-	1	-	-	-	-	-
MIXED	1	-	1	-	-	1	-	37	-	2	5	3

further increase the breeding potential of this species. The widespread destruction of irrigation works in the 10th century by South Indian invaders coincided with a simultaneous decline in rainfall. These factors produced conditions suitable for breeding *A. culicifacies* and marked the start of a series of malaria epidemics.

Agricultural practices have been changing during the past 20 years. The tractor is replacing the buffalo, particularly in the newly-opened lands under the Mahaweli Development Project. As the buffalo population rapidly decreases, the vector mosquito is diverted from animal to man, increasing the man-vector contact and the potential for malaria transmission. Recent cytogenetic studies revealed that *A. culicifacies* is a species complex comprising sibling species. The environmental changes associated with major irrigation projects may affect the existing balance between these sibling species and this may result in changes in the vectorial capacity of the species as a whole. Anophelines which are not playing a prominent role in malaria transmission at present, may become more important, as well.

Malaria Control

The activities carried out for the control of malaria in Sri Lanka can be divided into two distinct periods: 1) prior to November 1945, during which indoor application of residual insecticides was not used, and 2) after November 1945 when a malaria control program started systematically applying residual insecticides.

The malaria control measures carried out during what is generally known as the pre-DDT era were essentially anti-larval aimed at the prevention and reduction of mosquito breeding. They consisted of: 1) source reduction methods such as filling burrow pits, draining low-lying areas, and constructing and maintaining drains; 2) biological control by introducing larvivorous fish into water collections and wells; and 3) chemical control by applying oil and dusts such as Paris Green to water collections.

With the availability of DDT after World War II, the strategy changed from anti-larval operations to anti-adult measures. A program for malaria control using DDT was introduced in the latter part of 1945, and by 1947 all the malarious areas were brought under DDT coverage. It was used initially in a kerosene solution and sprayed at 6-week intervals at a dosage of one gram per square meter. The DDT-kerosene solution was changed to DDT emulsion and later to DDT suspension, and the interval of spraying increased from 6 to 12 weeks.

The results of this residual spraying program were spectacular. There was a drastic reduction in both malaria morbidity and mortality. Within five years, the spread of the disease had been interrupted in the epidemic zone, and a strategic withdrawal of spray operations in this zone began in 1951 and was completed by 1954. The withdrawal was largely influenced by development of resistance to DDT in vector mosquitoes in some parts of the world. Within a few months, there was an upsurge of malaria in the dry zone that necessitated resumption of DDT spraying.

The National Malaria Control Programme was converted into a Malaria Eradication Programme in late 1958, and had the objective of malaria eradication throughout the country. The success of the Eradication Programme was outstanding, with a remarkable reduction in the number of microscopically positive cases from 1,596 in 1959 to only 17 in 1963, 10 of which were introduced cases. A partial withdrawal of insecticide spraying was begun in 1963 and completed by mid-1964. However, localized outbreaks of malaria began to appear in late 1964 and spread to other areas. By 1968, DDT coverage was resumed in all areas where malaria occurred previously. With spraying operations firmly established, malaria morbidity began to subside in the subsequent years but, in 1975, there was a resurgence of the disease with an alarming increase in the incidence of *P. falciparum*. The situation was compounded by the development of DDT resistance in the vector mosquito, *A. culicifacies,* and DDT was replaced by malathion.

In 1977, an intensified malaria control program using malathion came into operation, largely through the generous assistance of US$.778 million (Rs 21 million) from a consortium of donors (United States, Netherlands, and the United Kingdom) for imported items such as malathion, vehicles, spraying equipment, etc.

Table 1 shows that there was a dramatic reduction of cases from 262,460 in 1977 to 69,685 in 1978 and, thereafter, a steady decline to 38,566 in 1982. The declining trend was reversed in 1983 and 1984 because of abnormal rainfall, and cases increased to 127,264 in 1983 and 149,470 in 1984. However, with the return of normal rainfall in 1985 and the resumption of antimalaria measures, there has been a significant reduction of malaria cases in the first half of 1985 compared to the corresponding period for 1984.

Though there has been an overall reduction of cases, a danger signal is the relative increase of *P. falciparum* infections, especially among the population in the Mahaweli Project, Systems B and C (Table 2). The malaria problem in Sri Lanka today is a matter of grave concern with water resource development activities underway in the dry zone, disturbed conditions in the North and East, emerging technical problems of incipient vector resistance to malathion in some areas, detection of a focus of resistant *P. falciparum,* a gradual decline in spray coverage and increasing non-acceptance of radical treatment, increasing costs of malaria control, and shrinking foreign aid.

A change is required from the present strategy of malathion spraying and case detection and treatment, to one of integrated control. It will be necessary to supplement malathion spraying with: 1) water management practices, 2) biological control and larviciding in suitable situations, 3) intensified case detection activities with medical institutions playing a more active role, 4) a well-planned operational research program, 5) mobilization of community support for acceptance of anti-malaria activities, and 6) collaboration of health related sectors.

Study of Mosquito-Borne Diseases in Some New Irrigation Schemes in Sri Lanka, with Particular Reference to Filariasis and Arboviral Diseases

Tissa Vitarana, Pushpa Herath, Kingsley Kalpage, Nalini Jayasekera, Mervyn Wickremasinghe, and Varuni Gunatilake

Introduction

Although the Anti-Malaria Campaign has carried out data collection on mosquito-borne diseases in Sri Lanka's new irrigation areas, little or no information has been obtained concerning the transmission of filariasis and arboviral diseases. A World Health Organization/Panel of Experts for Environmental Management (WHO/PEEM) study was designed to provide some of the missing information. This paper is an interim report.

Past experience in Sri Lanka indicates that the vector-borne diseases needing investigation fall into three categories: 1) those arising as a direct consequence of new irrigation works (malaria and Japanese encephalitis); 2) those due to associated population movement, concentration, and urbanization (filariasis and dengue); and 3) those due to the opening of new jungle land when man may become involved in an existing sylvatic cycle of infection. Examples of the latter would be tick typhus and Kyasanur Forest disease (KFD) which is found in Mysore, India. Both of these are tick-borne diseases, yet the possibility of similar mosquito-borne diseases also exists.

Japanese Encephalitis (JE). This is a major health problem in many parts of Asia with an increasing number of cases reported in India, China, and Southeast Asian countries such as Thailand. It is a severe illness with a high fatality rate (20-65%) and a high degree of residual disability (paralysis, fits, etc.) in survivors.

In Sri Lanka, encephalitides form an important health problem, accounting for an annual average of 1,030 hospital admissions and an average case fatality of 38% (range of 25-45%). Studies[1] suggest that JE accounts for 43% of the diagnosed cases. The disease appears to be endemic in Sri Lanka with imported cases occurring sporadically. Although major epidemics have not occurred, a few outbreaks have been reported in Kurunegala, Jaffna, and Vavuniya. Serological surveys indicate that JE occurs in certain parts of the country such as the western coastal areas, Kurunegala, Anuradapura, and Batticaloa districts, and around Tissamaharama. Although there is no specific treatment for JE, the prevalence is not considered high enough to justify an immunization program. However, there is no doubt that it is presently a more important problem in Sri Lanka than poliomyelitis.

The main vector of JE in Sri Lanka, *Culex tritaeniorhynlus,* breeds in rice fields, and its distribution pattern is therefore closely associated with ancient and newly developed irrigation schemes.

Dengue. Endemic in Asia for decades, Dengue has become a major disease and cause of death in children in Southeast Asia since the appearance of the Dengue Haemorrhagic Fever (DHF) in 1954. Last year in Thailand alone there were 60,000 cases of DHF.

Studies[2] indicate that dengue is endemic in Sri Lanka, occurring in most areas below an elevation of 914 meters with maximum incidence in Colombo. A few cases of DHF occur each year, with a slight upward trend of 7 cases (one death) in 1983 to 8 cases (one death) in 1984.

Filariasis. Filariasis is believed to be endemic in

[1]Vitarana, T. 1982. *Viral Diseases in Southeast Asia and the Western Pacific.* Academic Press. pp198-204.

[2]Vesenjak-Hirinjan, J., et al. 1969. *Bulletin of the World Health Organization* 41:243, and others.

the coastal belt extending from Puttlam in the northwest to Tissamaharama in the south. It is a cause of fever, lymphoedema, epididymo-orchitis, and tropical eosinophilia. No studies have been done in the Mahaweli Area.

The vectors of dengue, *Aedes aegypti* and *Aedes albopictus,* and the main vector of lymphatic filariasis, *Culex quinquefasciatus,* breed most abundantly in areas of human settlement. Their presence is thus indirectly linked to irrigation development in as far as such development tends to concentrate people in new settlements.

Study Plan

Ideally, a preliminary study to obtain baseline data should have been done before the irrigation works commenced and new settlers moved in. Unfortunately, in the main study area - Mahaweli Project, System C, Zone 2 (Mahaweli C2) - most areas were already irrigated and new settlers established by the time the study began. The original area selected outside the Mahaweli Project was in the Muthukandiya Reservoir Project. However, this had to be changed because of unrest in the area. The Lunugamvehera Project was substituted. Here the irrigation works were still underway and, although new settlers had moved in, no water had been supplied for agriculture.

Some data on malaria were available for both areas. No data on filariasis are available for the Mahaweli area but there are figures for Tissamaharama, which is a part of the Lunugamvehera study area. In 1984, 10,616 blood films were examined of which four were positive. This gave a microfilaria (MF) rate of 0.03. In previous years the MF rates were 0.14 (1978-1979), 0.18 (1980), 0.08 (1981), 0.07 (1982), and 0.02 (1983).

Some information had been obtained on JE and dengue from surveys done in Tissamaharama in 1976 and in Damana and Maha Oya (which are close to Mahaweli C2) in 1978. In all three areas the presence of antibodies in the sample population indicated JE infection. A 1976 survey detected JE and dengue antibodies in the populations of Badulla and Batticaloa, the two main towns bordering System C. Dengue antibodies were not detected in Tissamaharama, Maha Oya, or Damana.

Phase 1 of this study was conducted during January-February 1985 (Mahaweli C2) and March 1985 (Kirindi Oya). This wet season study took three weeks in each project area. Phase 2 was carried out in a similar way in the dry season, in August and September respectively.

Selection of Villages and Hamlets. The objective was to obtain a sample that would represent the area geographically and also include a suitable mix of resettlers (those who moved within the same area) and new settlers (those who migrated from other parts of Sri Lanka). In Mahaweli C2, Rotalawela had all new settlers, Divulapelessa and Belaganwewa had a mostly new settlers, Alutharama had only resettlers, and Galporuyaya had a majority of resettlers. A new township was included in each area: Girandurukotte in Mahaweli and Lunugamvehera in Kirindi Oya. Because many resettlers had been in the area for 5-15 years, the virological age-stratified study included a traditional village in each area: Hembarawa in Mahaweli and Gemunupura in Kirindi Oya.

Malaria and Filariasis Studies. As far as possible the entire population in the selected areas was blood filmed at night (after 20:30), once during the rainy season (February and March) and again during the dry season (August and September). The films were stained and examined microscopically for malarial parasites and micro-filaria.

Virological Studies.

1. *A fever case study.* Blood samples from possible acute and convalescent viral fever cases attending the two hospitals (Girandurukotte and Lunugamvehera) were tested serologically for known arboviruses. Virus isolation was attempted from acute samples stored at -70°C using baby mice, mosquitoes, and a variety of cell cultures. The objective was to isolate known or hitherto unknown viruses present in the study areas.

2. *A serological study.* An age-stratified study of a sample of traditional settlers was done on the first visit to obtain the antibody profile and determine the past occurrence of known arbovirus infections (dengue, JE, chikungunya, and sindbis). The second part was a study of children under five years old of new settlers. These children were bled on both visits

to detect new virus infections occurring during the study period (i.e., the infection rate). In hamlets where the sample of new-settler children was inadequate, re-settler children under 10 years old were included. For the serological study two filter paper discs were soaked with blood on each occasion and, after drying, the serum was extracted and tested for antibodies by Clarke and Casals' modified Haemagglutination Inhi-bition (HI) test. From some of the HI positives which showed antibodies against dengue and JE, venous blood was collected and tested by a Neutralization Test (NT) using mice to establish the type of infecting virus. In view of the positive human JE, blood was collected from pigs on a farm in Tissamaharama and tested by HI and NT.

Results

Malaria. An overall increase in malaria positives from 0.49% to 1.23% occurred in Mahaweli C2 during the study period (Table 1). The increase seems to occur in all age groups but in children under 5 years old (who were negative at the first bleed), 11 new positives appeared, including an infant. A disturbing feature is the increase of *Plasmodium falciparum* cases (from 1 to 6) and of *P. vivax cases.*

It is noteworthy that in the township of Girandurukotte, where residual insecticide spraying is probably most effective, there were no positives on the second occasion. Two of the three hamlets (Rotalawela and Belaganwewa) with the most new settlers (who are likely to be non-immune), showed new positives at all ages, whereas both had no cases on the first occasion. Although Divulapelessa remained static at six positives, the appearance in three children under five years of age indicates continuing activity.

In Kirindi Oya the situation has remained more static with practically no positives in Lunugamvehera (Table 2). But there is continuing activity in Hamlets 5 and 6 with more being affected under five years of age in the latter. The increase of P. falciparum cases to five in Hamlet 6 is noteworthy.

Table 1. Prevalence of malaria in selected localities in Mahaweli system C, February and August 1985.

	Giranduru-Kotte		Divulapelessa		Belaganwewa		Rotalawela		Galporuyaya		Alutharama		Total	
	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug
No. tested	260	783	511	826	334	644	334	833	359	-	237	-	2035	3086
No. positive	1	-	6	6	-	4	-	28	3	-	-	-	10	38
Percentage	0.7	-	1.2	0.7	-	0.6	-	3.4	0.8	-	-	-	0.5	1.2
P. vivax	1	-	6	3	-	3	-	26	2	-	-	-	9	32
P. falciparum	-	-	-	3	-	1	-	2	1	-	-	-	1	6
Sex: M/F	0/1	-	4/2	3/3	-	1/3	-	13/15	3/0	-	-	-	7/3	17/23
Age: <1	-	-	-	-	-	-	-	1	-	-	-	-	-	1
1-5	-	-	-	3	-	-	-	7	-	-	-	-	-	10
6-10	-	-	1	-	-	1	-	3	-	-	-	-	1	4
11-15	-	-	2	-	-	-	-	2	-	-	-	-	2	2
>15	1	-	3	3	-	3	-	15	3	-	-	-	7	21

Table 2. Malaria incidence in selected localities at Kirindi Oya, March and September 1985.

	Lunugamvehera Mar	Lunugamvehera Sep	Hamlet 5 Mar	Hamlet 5 Sep	Hamlet 6 Mar	Hamlet 6 Sep	Hamlet 11 Mar	Hamlet 11 Sep	Total Mar	Total Sep
No. tested	273	324	-	576	413	483	151	394	837	1777
No. positive	-	1	-	3	19	25	-	-	19	29
Percentage	-	0.3	-	0.5	4.6	5.2	-	-	2.3	1.6
P. vivax	-	1	-	3	18	20	-	-	18	24
P. falciparum	-	-	-	-	1	5	-	-	1	5
Sex: M/F	-	1/0	-	2/1	10/9	18/7	-	-	10/9	21/8
Age: < 1	-	-	-	0	-	-	-	-	-	-
1-5	-	-	-	0	5	8	-	-	5	8
6-10	-	-	-	1	3	2	-	-	3	3
11-15	-	-	-	0	2	2	-	-	2	2
> 15	-	1	-	2	9	13	-	-	9	19

Filariasis. Table 3 shows that the microfilaria positive rates are low in both Kirindi Oya (0.14%) and Mahaweli C2 (0.09%). The three positives are among people who have come recently from outside the area. In view of the vector presence the possibility of spread to others in the area exists. The concentration technique was not used in testing.

Table 3. Prevalence of lymphatic filarisis[a/] in selected localities in Mahaweli System C and Kirindi Oya, February 1985.

	No Tested	Positive Number	Positive Percentage
Mahaweli			
Girandurukotte	472	1[b/]	0.21
Divulapelessa	559	-	-
Belaganwewa	336	-	-
Rotalawela	360	-	-
Galporuyaya	389	-	-
Millettewa	229	1[b/]	0.44
Sub- Total	2345	2	0.09
Kirindi Oya			
Lunugamvehera	151	-	-
Hamlet 6	507	-	-
Hamlet 11	70	1[c/]	1.4
Sub- Total	728	1	0.14
Total	3073	3	0.1

a/ Measured as the microfilaria rate;

b/ employed as drivers by the Mahaweli Authority and originally from the south (not settlers);

c/ a female new settler from Matara.

Virology. Past virus activity is assessed on the basis of age stratified studies (Table 4). The interpretation of the results has been difficult due to the detection by the HI test of three types of response: a) true positives where antibodies to both JE and dengue occurred, b) questionable positives where only JE antibodies occurred, and c) non-specific inhibitor type responses (NSI) where both JE and sindbis "antibodies" were present. More investigation, including the Neutralization Test on freshly collected venous blood will be needed in order to interpret results more clearly. The preliminary indications are that JE virus has caused sporadic infections in both Mahaweli C2 and Kirindi Oya, and that a few people have had dengue and chikungunya infections but these may have occurred outside the study areas.

Two hundred of the 389 Mahaweli C2 specimen pairs were tested to determine the extent of new virus infections. Only five showed sero-conversions to both JE and dengue but at low levels. These results need to be confirmed by NT, before it can be concluded that JE transmission is occurring. The Kirindi Oya specimens have not yet been tested. The blood samples from convalescent fever cases have yet to be collected and tested.

Of nine pigs bled from Tissamaharama, eight showed evidence of a flavivirus infection, and two tested by NT were confirmed positive for JE. This includes young pigs, and confirms that JE transmission occurs in this area.

Table 4. Past arbovirus infections, number and percentage of positive case for Japanese encephalitus, dengue, and chkungunya in selected localities in Mahaweli System C and Kirindi Oya[a/]

	Total collected	Total tested	JE pos	JE ?pos	JE NSI	Dengue	Chikun-gunya
Mahaweli							
Hembarawa	363	363	8	84	111	8	1
Alutharama	56	56	7	38	1	7	1
Galporuyaya	285	285	5	89	118	6	-
Divulapelessa	118	118	9	66	8	9	-
Millettawa	53	13	-	2	11	-	-
Sub-total	911[b/]	835	29	279	249	30	2
Percentage			3.5	33.4	29.8	3.6	0.2
Kirindi Oya							
Gemunupura	203	203	5	97	39	5	-
Percentage			2.5	47.8	-	2.5	-
Total	1114	1038	34	376	288	35	2

a/ as detected by the indirect haemagglutination inhibition (HI) test;

b/ Belaganwewa, 36 were collected but not tested.

Conclusions

This preliminary study permits some general observations. There is no doubt that both *vivax* and *falciparum malaria* are active in the study areas. There is some evidence of JE, but more work is needed to confirm this. There is a definite risk of spreading filariasis in both areas but further studies are required. Dengue and chikungunya are not yet problems, but follow-up is indicated. The detection of any new agents, particularly viruses, requires further study of fever and other clinical cases.

Acknowledgements

We acknowledge the dedicated work of the field staff from the Malaria and Filariasis Departments and the MRI, and the intense effort of all the laboratory staff who cooperated so readily.

Current Studies on Vector Populations in Areas Under Development in Mahaweli System C[1]

F. P. Amarasinghe[2]

The research project on mosquito-vector biology in Mahaweli System C described in this paper has two major objectives. The first is to make a three-to four-year study on the effects of ecological changes associated with forest clearing, human settlement, and development of irrigated agriculture on mosquito ecology, especially in relation to vectors or potential vectors of human arboviral, nematode, and protozoan diseases. The second objective is to determine natural vector incrimination and competence by investigating the local mosquito fauna for evidence of parasite carriage in the field as well as in the laboratory, particularly in relation to arboviruses and nematodes.

The arbovirus study is based on: 1) attempts to isolate viruses from field-caught mosquitoes; 2) sero-epidemiological surveys of human and animal blood, including a longitudinal follow-up started in August 1985 of cohorts of human settlers newly translocated to System C; and, 3) laboratory virus-vector competence studies on selected mosquito species based on the evidence gathered from field isolation and sero-epidemiological surveys.

The study of parasitic nematodes, which has just begun in System C, involves nematode isolation in field-caught mosquitoes, blood surveys, and transmission experiments in the laboratory. This study also involves a parallel project on mosquito ecology and vector incrimination in the hill-country habitat of urban Kandy where both virological and nematological studies are underway.

This paper will present some of the results of the first phase of the study which is the baseline survey of the mosquito fauna in the dry zone secondary forest habitat prior to clearing and development.

Study Sites and Methods

Mahaweli System C, Zone 4, Block 6 was selected as the study area because it included the three necessary phases to the study: forested, clearing and human settlement, and irrigated agriculture. Figure 1 shows the three sites selected within Block 6 - on the right bank of the Mahaweli River along the western boundary (MRS); the eastern side in the Dehiattakandiya-Hungamala Oya area (DKD/HUN); and in the central Bakmeedeniya area (BAK). A fourth site, in Zone 5 (approximately 0.5 km north of Block 6), was selected as a control because the development of this area is expected to take place at a later date.

The research project began in early 1984 when Block 6 was uninhabited except for the Dehiattakandiya township, then under construction. The riverine forest was largely intact, although somewhat degraded by the cutting of commercially valuable timber over the previous three to four years. There has been a progressive degradation of the forest environment over the past 16 months as the infrastructure of Block 6 was constructed and large numbers of people moved into the area, extracting timber and firewood or destroying the forest for "chena" (slash-and-burn) cultivation. At present, only isolated patches of the riverine forest remain. The study sites, which were virtually intact until August 1985, are now under pressure. The forest at BAK site is almost totally cleared, while the areas around MRS, HUN, and DOL have been degraded. The influx of the first settlers into the Block 6 Nagaswewa area in August 1985 moved the survey into its second phase.

[1] Research cnducted by a multidisciplinary team drawn from the Departments of Zoology, Microbiology and Parasitology of the University of Peradeniya, Sri Lanka.

[2] Department of Zoology, University of Peradeniya.

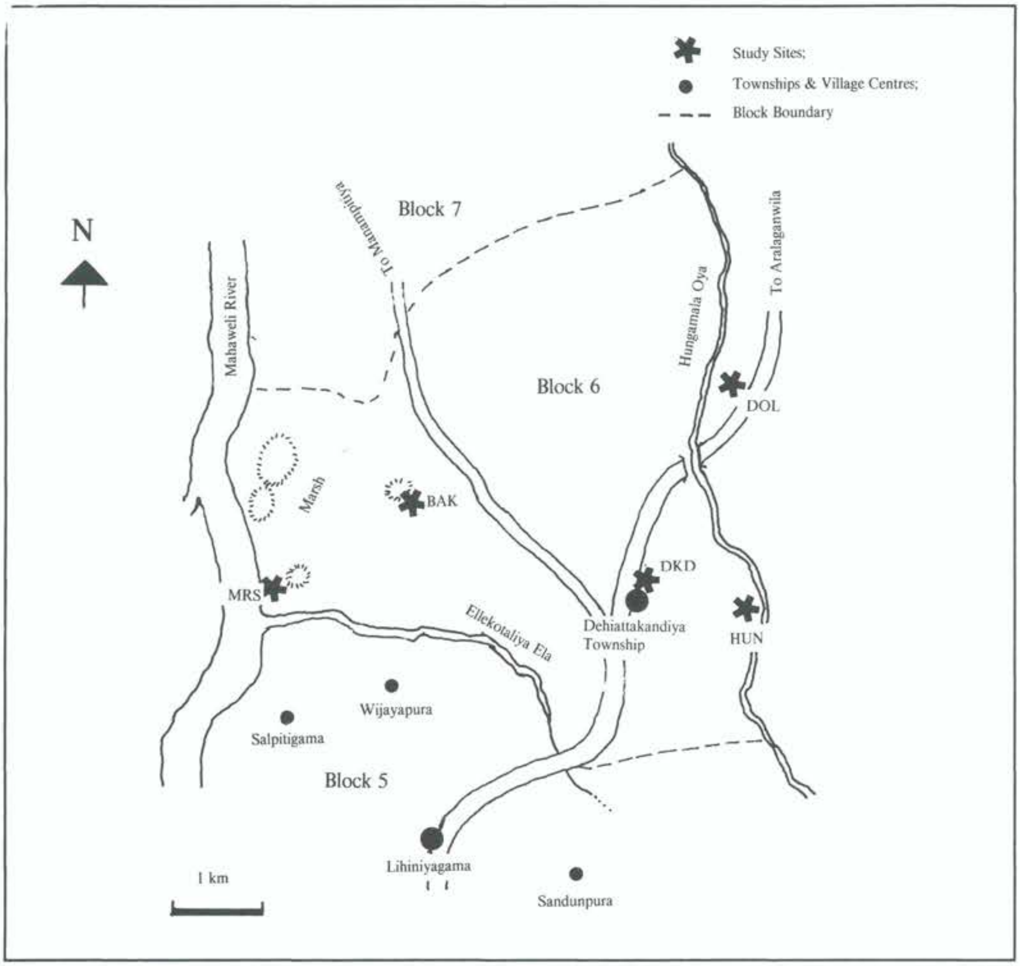


Figure 1. Block-6, Zone-4, Mahaweli System-C

The core field team of six made monthly field visits. As the emphasis of the project is on man-biting mosquitoes, the human-bait catch was the principle method used for adult mosquito collection. Cattlebait catches, which usually yield larger numbers of species (including those which attack man), were not a realistic option under the working conditions in the forest. Diurnal human-bait catches were made by two 2-person teams collecting for 20 minutes at each of 3-5 catch stations along a forest transect at each study site. The collections were always done at the time of maximum activity of diurnal mosquitoes, 14:00-17:00 hours. This was followed by a stationary nocturnal catch at each site lasting for six hours. The catch began at sunset (half-night catch) and employed two-person teams working in rotation. CDC-light traps (two traps per site) were used as an additional survey method, especially for non-man-biting species. Night collections of resting mosquitoes were taken from the small thatched huts *(waadiyas)* used by wood cutters in the vicinity of the sites, with one man using a battery-powered aspirator to collect for 15 minutes from each hut. These were opportunistic collections. Larval collections from container and groundwater habitats were made by a two- or three-member team covering approximately 0.25 square kilometer at each site and beginning around 13:00 hours. The entire contents of tree holes and other container habitats were sampled, while groundwater habitats were sampled by dipping according to effective breeding water surface area at the rate of six dips per square meter. Taxonomic identification of all material was made by the author.

Results and Discussion

Eighty species of mosquitoes were identified from adult and immature collections made from June 1984 to September 1985, with a total collection of 11,222 adults and 33,330 immatures.

Survey of adults. The results of the adult collections of mosquitoes are summarized in Table 1. The CDC-light trap was the most successful method in terms of species diversity, while human bait was more efficient in terms of numbers of specimens. The overall diversity index indicates a heterogenous habitat supporting a diverse mosquito fauna.

Thirty species were encountered in diurnal bait catches but only one, *Aedes albopictus,* is a known vector of human disease and is implicated in the transmission of dengue virus in Southeast Asia. It was prevalent in the forest sites at a fairly high landing/biting rate, being especially abundant during the monsoonal (October-January) and post-monsoonal (February-May) periods (Table 2). Thus, there is an established sylvan population of a highly anthropophilic peridomestic species.

Significantly, not a single adult or immature of another diurnal anthropophilic mosquito, *Aedes aegypti,* the principal vector of dengue in our region, was collected. This reconfirms the very close association between this vector and humans, its principal host. True sylvan populations of *A. aegypti* are

Table 1. Summary of adult mosquito collection, June 1984 - May 1985.

	Human Bait (diurnal)	Human Bait (nocturnal)	CDC light traps	Huts	All
Man-hours	277	559		22.5	58.5
Trap-nights			96		96
Species	30	47	50	28	70
Specimens	2662	6553	1185	822	11,222
Diversity[a/]	0.90	0.92	1.27	0.67	1.20

[a/] Shannon-Weaver.

Table 2. Potential vector species of mosquitos collected using human bait.

	Species	No. Females	LB Rate[a/]	Sites[b/]
Diurnal				
	Aedes albopictus	670	2.41	all
Nocturnal				
	Mansonia annulifera	3328	5.95	all
	M. uniformis	212	0.38	all
	M. indiana	175	0.31	MRS/BAK
	Culex gelidus	514	0.92	all
	C. fuscocephala	341	0.61	all
	C. tritaeniorhynchus	338	0.60	all
	C. pseudovishnui	273	0.49	all
	C. quinquefasciatus	54	0.09	DKD/BAK
	Armigeres subalbatus	272	0.49	DKD
	Anopheles varuna	139	0.25	all
	A. vagus	121	0.22	all
	A. culicifacies	63	0.11	all

[a/] Landing/Biting Rate (females/man-hour);

[b/] BAK Bakmeedeniya, DKD Dehiattakandiya, MRS Mahaweli River Site.

rare and the spread of this mosquito usually follows closely upon the heels of human colonization.

The nocturnal human-bait collections yielded several species which could be regarded as potential vectors of human disease. All three species of *Mansonia* that occur in Sri Lanka were present, with *M. annulifera* the most prevalent biter during all seasons. However, its distribution was highly localized, occurring in overwhelming numbers at the MRS (18.7 females/man-hour), to a much lesser extent at the BAK site (2.7 females/man-hour), and scarce at the other two sites. The distribution pattern of these three species was determined by the location of their main breeding site, a large Pistia-covered marsh *(villu)* in the jungle approximately 0.75 kilometer north of the MRS and 3.5 kilometer west of the AK site. Quantitative estimates taken in late September and early October 985 showed the density of *M. annulifera* to be 90-94 immatures/square meter of Pistia cover. At this density, the approximately 4,000 square meters under Pistia cover after the monsoonal rains would generate around 360,000 to 376,000 immatures of this species at any given time.

Three *Culex* species (C. *tritaeniorhynchus, C. gelidus,* and *C. fuscocephala)* implicated in the transmission of Japanese encephalitis (JE) were collected by human bait mainly during the rainy and post-rainy seasons, and at low overall biting rates. *C. pseudovishnui,* another species that may be involved in JE transmission, was also collected.[3] Most of these species are primarily zoophilic in their feeding but will attack man in the absence of other large (usually bovid) mammals. *C. quinquefasciatus,* the vector of bancroftian filariasis in Sri Lanka, occurred almost exclusively in the developing township of Dehiatta-kandiya (DKD), a site with an increasing number of residents, permanent housing, and septic tank drain-age systems. Only one biting female was collected outside this area, at BAK, during a period when 15-20 woodcutters were temporarily resident at the site. It seems reasonable to postulate that this species is a new invader of this habitat, moving in rapidly with the human population.

There is evidence to suggest that *Armigeres* subal-batus (a vector of setarial and dirofilarial nematode infections, chiefly in bovids), may have spread into the forest with human migration or, if previously present at low abundance, is now increasing rapidly in developing townships. It has been encountered frequently in the townships of Dehiattakandiya, Sandunpura, Lihiniyagama, and Siripura. In crepuscular-nocturnal catches this species was collected only from the DKD site and not from the forested sites. However, diurnal catches yielded a few biting females from forested areas, initially at HUN and BAK, the two sites closest to Dehiattakandiya, and later at the other two sites. Its main breeding locations in the forest were in habitats associated with human activity, such as the stump holes of newly-felled trees and artificial containers. It is quite possible that this large and powerful flier may have spread from DKD township into the surrounding forest, rather than the other way around.

Small numbers of A. vagus, *A. varuna,* and *A. culicifacies* were collected regularly from all sites. Although too low for detailed analysis, the numbers indicate that *A. culicifacies* was most prevalent during the late post-monsoonal and dry season. It is evident that the sylvan population of this species will feed on humans in the forest and the many instances of malaria among woodcutters and construction workers in the area could have been due to local transmission by this species, by far the most important natural vector of malaria in Sri Lanka. The chances of transmission would also have been increased by the endophagic habits of this population. The hut collec-tions show that *A. culicifacies* females were collected at night inside occupied woodcutters huts and the majority were freshly fed, almost certainly upon human hosts (Table 3). Thus, hut collections also provide further evidence of the link between the DKD township and A. subalbatus and *C. quinquefa-sciatus,* with all specimens of the former and 91% of the latter being collected from this site.

The CDC-light traps were not efficient in attracting large numbers of any one species but regularly caught the five species listed in Table 4. About 30-40% of females of the 3 Culex species were either half or fully gravid, a component of the population that is not generally sampled in bait catches. The trap could be a useful method of surveying this

[3]Sirivanakarn, S. 1976. A revision of the subgenus Culex in the oriental region (Diptera: Culicidae), *Medical Entomology Studies, III. 12(2):1-272.*

Table 3. Potential vector species of mosquitos resting in huts.[a]

Species	No. Females	LB Rate[b]	Sites[c]
Mansonia annulifera	488	21.69	MRS/BAK/DOL
Culex quinquefasciatus	145	6.44	DKD/BAK
Armigeres subalbatus	52	2.31	DKD
Anopheles culicifacies	14	0.62	MRS/BAK/DOL

component of the *C. tritaeniorhynchus* population. In Kandy, where it is abundant, this species is collected regularly in the CDC-light traps at a rate of 2.2 adults per trap/night. The Kandy project has also shown that this trap is very useful for monitoring populations of *Anopheles aconitus,* a species which seems to be extremely rare in Sri Lanka's dry-zone forest habitat.

Data relating to the main container-breeding species are presented in Table 5. *Aedes albopictus* was the most prevalent species and occurred in all the habitat types, including artificial containers such as coconut shells, tins, and a tyre. The sylvan population of this vector species may adapt successfully to a peridomestic existence in a post human-settlement. As mentioned previously, *A. subalbatus* seems to prefer habitats associated with recent human activity, particularly holes in newly-cut tree stumps that contain foul water.

Table 4. Main Mosquito species at CDC light traps.

Species	No. Adults	LB Rate[a]	Sites
Mimomyia hybrida	249	2.59	all
Culex pseudovishnui	128	1.33	all
C. nigropunctatus	88	0.92	all
C. tritaeniorhynchus	80	0.83	all
Anopheles varuna	78	0.81	all

[a] Landing/Biting Rate (females per man-hour)

Survey of immatures. So far immatures of 63 species were collected during this study, with 29 being recorded from container habitats and 49 from ground water habitats.

Table 5. Main mosquito species breeding in container habitats.[a]

Species	N	Tree pot-hole	Tree pan	Tree stump	Artificial container	All
Aedes albopictus	993	0.66	2.64	2.73	3.48	1.82
A. novalbopictus	259	0.18	0.95	0.44	0.26	0.52
A. aureostriatus	128	0.50	0.35	--	--	0.31
Armigeres subalbatus	118	0.02	0.21	1.90	0.42	0.28
No. of samples		62	65	14	09	150
Mosquito positives	(%)	56	68	86	100	67

[a] Immatures per dip/positive sample expressed as geometric mean.

Table 6 presents data on some of the important groundwater breeding species. The classifications of groundwater habitats used in this study reflect the main types of ecological habitat suitable for breeding in the forest, as well as their seasonal availability. Forest-floor pools, animal footprints, and flowing water were available chiefly during the monsoon and post-monsoonal periods, while stream- and river-bed pools were essentially a dry season habitat. The availability of the marsh habitat varied with the size. Two of the smaller marshes sampled dried out during the peak of the dry season but two large ones retained water throughout the year.

Table 6. Main mosquito species breeding in ground water habitats.[a/]

Species	Forest floor pools	River/ stream pools	Marsh	Animal foot-prints	Flow water margins	All
Culex mimulus (N 15390)	0.43	0.43	0.08	0.05	(0.004)	0.27
C. pseudovishnui (N 2328)	0.005	0.005	0.39	-	-	0.099
C. fuscocephala (N 511)	0.03	0.03	0.02	(0.009)	-	0.03
C. tritaeniorhynchus (N 359)	0.02	0.008	0.03	-	-	0.02
C. gelidus (N 321)	0.009	(0.009)	0.03	-	(0.001)	0.01
Aedes vittatus (N 2027)	0.35	0.01	-	-	-	0.08
Anopheles culicifacies (N 1437)	(0.0001)	0.38	-	0.05	-	0.14
A. barbirostris (N 1300)	0.08	0.15	0.02	0.05	0.02	0.11
No. of samples	246	486	160	83	43	1018
% mosquito positives (%)	54	45	96	41	37	55

a/ Immatures per dip/positive sample are expressed as geometric mean.

The most abundant ground-breeding mosquito was *Culex mimulus* (a non-vector species) that occurred regularly in all standing-water breeding sites and at highest densities in forest floor and waterway pools. By comparison, other *Culex* species, such as *C. tritaeniorhynchus, C. gelidus, C. bitaeniorhynchus, C. fuscocephala,* and *C. pseudovishnui,* that have been implicated in the carriage of viral or nematode infections occurred at much lower relative abundance levels. This shows some correlation with the low biting rates at bait catches and is indicative of low overall abundance in the habitat. *Aedes vittatus* was the only important ground-breeding species, breeding exclusively in rock pools on the forest floor and stream/river beds. This species is recognized as a vector of yellow fever in Africa but has not been implicated in disease transmission in the Orient.

Two of the most frequent of the 14 anopheline species recorded in this survey, *A. culicifacies* and *A. barbirostries,* present an interesting comparison of breeding strategy. The sylvan *A. culicifacies* occurred at a high frequency and abundance level in stream- and river-bed pools, which are clearly identified as its major breeding habitat. Surprissingly, there were very few immatures from rain water pools on the forest floor (even fully exposed pools) or stream margins, two habitats in which this species is reported to occur frequently[4]. Its virtual restriction to natural waterway pools implies that it is primarily a dry season species in this particular forest habitat. Occupation of animal footprints, chiefly elephant, by this species occurred towards the end of the post-monsoonal period, invariably on the banks or drying beds of streams. Analysis of the data gathered during the first 12 months of the survey supported previous observations (ibid.) that this species exhibits a distinct preference for clear water pools (versus turbid, foul water pools) and pools exposed to sunlight (versus shaded and semi-shaded pools). *A. barbirostries* occurred frequently in all habitat types but at low abundance levels.

Malaria is the primary vector-borne health hazard in this area, with *A. culicifacies* the chief natural vector. The first year of the study provided evidence of frequent breeding occurrences of this species in stream-and river-bed pools. Hence a survey was carried out during the 1985 dry season to identify the main breeding locations of this species in Block 6. Block 6 is bounded by three natural waterways, the Hungamal Oya on the east and north, Ellekotaliya Ela on the south, and Mahaweli River on the west (see Figure 1). To the best of our knowledge, the only other natural bodies of water existing during the dry season in this area were two large marshes occupying approximately 13,000 square meters. The Hungamala Oya is a 14-20 meter wide stream with an even sandy bed. In contrast to this, Ellekotaliya Ela is narrow (7-13 meter) with an uneven rocky bottom. Both streams were surveyed by 1-2 kilometer transects. The Mahaweli River bed in this stretch of System C has many rocky outcrops where pools are formed as the water level recedes during the dry season. Transect sampling along the river was not a feasible option so a large rock outcrop in the river bed was selected just below the southwestern tip of Block 6. The two marshes were sampled at the same time but as they did not yield any A. *culicifacies.* These data are not included in the results (Table 7). The data shows that the topography of the Hungamala Oya did not favor water retention or natural pool formation; by July only human-dug pools remained along the eastern transect, while one natural pool and a few human-dug pools remained along the northern transect. This stream yielded only one positive sample of *A. culicifacies.* By contrast, the rocky uneven terrain of the Ellekotaliya Ela resulted in pool formation and water retention, which also occurred on the rock outcrop in the Mahaweli River. Both these sites were regularly utilized by *A. culicifacies,* as indicated by the overall number of positive samples (89), total number of immatures (1,030), and the density values in terms of immatures per dip/positive pool (geometric mean of 0.56-0.59).

The study also provided some interesting insights into the influence of river water level on the dynamics of breeding. For example, in mid-July heavy ups-tream monsoonal activity resulted in a massive water release from the Victoria Dam that completely submerged both the river rock pools and the Ellekota-liya Ela for over a week, flushing out the mosquito immatures. By August, the flood waters had receded and the pools reformed, providing suitable breeding sites for *A. culicifacies.* In mid-September, a two-foot rise in the river level (probably caused by water release from Victoria Dam) was successful in flushing out all but the highest pools on the rock outcrop, again adversely affecting the breeding of this Ano-pheline. Conditions in 1985 caused much more disruption of *A. culicifacies* breeding at this focus than in 1984: the monsoon was not as heavy, Victoria Dam was not operational, and the river water level did not fluctuate so widely.

The implications for water management are obvious. Despite an occasional flushing out, there is no doubt that this species bred successfully at the Ellekotaliya-Mahaweli focus in 1985. It is perhaps significant that nearby areas in Block 5 were the focus of an outbreak of cerebral malaria that peaked during the 1985 dry season. There is no doubt that malaria will be the most immediate vector-borne disease problem to be faced by new settlers in this area.

[4]Harrison, B.A. 1980. The Myzomia series of Anopheles (Cellia) in Thailand, with emphasis on intro-interspecific variations (Diptera: Culicidae), *Medical Entomology Studies, XIII* 17(4):1-195.

***Table** 7. Anopheles culicifacies* breeding in Mahaweli System C, zone 4, block 6 during the dry season, June-Sept 1985.

	Hungamala Oya		Ellekotaliya Ela	Mahaweli
Transect (km)	02	02	1.5	-
Gross area (sq m)	32400	27680	14490	2500[a/]
June 13-16				
ASW[b/]	554	395	2802	814[c/]
% of gross area	1.71	1.43	19.33	32.57
No. of pools	25	16	36	62
No. *Ac* positive[d/]	01	-	07	08
July 16-18			e/	f/
ASW	35	117		
% of gross area	0.11	0.42		
No. of pools	08	06		
No. *Ac* positive	--	--		
August 15-17				
ASW	4	114	975	357
% of gross area	0.01	0.41	6.73	14.27
No. of pools	04	04	41	60
No. *Ac* positive	-	-	16	47
September 15-18				
ASW	2	42	553	893[g/]
% of gross area	0.006	0.15	3.82	35.72
No. of pools	03	02	20	96
No. *Ac* positive	-	-	08	03
September 26-28[h/]				
No. of immatures	05	-	496	534
Immatures/pool[i/]	(05)	-	1.17	0.98
Immatures/pool[j/]	-	-	0.56	0.59

[a/] Rocky outcrop on river bed; [b/] Area of standing water (square meters); [c/] Approx. 2-3 weeks post-pool formation; [d/] *A. culicifacies;* [e/] flooded due to monsoonal water release from Victoria Dam; [f/] flooded due to back flow from river; [g/] 48 host post-flushing rise in river water level; [h/] no data collected due to extensive flooding; [i/] immatures per dip/positive pool, arithmetic mean; [j/] immatures per dip/positive pool, geometric mean.

Acknowledgements

I wish to acknowledge with gratitude the financial assistance provided by the US National Academy of Sciences through a grant from USAID; the directorate and field officers of the Mahaweli Authority of Sri Lanka for their cooperation; Dr. William K. Reisen, consultant on the project, for his helpful advice during the initial stages of this work; and very specially, the entomology field team whose cheerful acceptance of the hard work and risks involved in a jungle survey are deeply appreciated.

Study of Vector Aspects of Mosquito-Borne Diseases in Some Irrigation Schemes in Sri Lanka

P. R. J. Herath[1], N. Jayasekera, K. Kalpage,
M. B. Wickremasinghe, V. Gunatilake, W. M. Nanayakkara.

Water resource development in Sri Lanka dates back several centuries. In recent times the Government of Sri Lanka has undertaken a number of multipurpose water development projects primarily to increase agricultural production and hydroelectric power generation, and to generate additional employment. Environmental changes associated with development of irrigated agriculture and human settlements are known to have a great impact on vector-borne diseases. This paper presents preliminary findings from two projects investigating the relationship between water development systems and mosquito vectors.

Project 1

The primary objective of Project 1 was to determine the prevalence and abundance of the mosquito vectors and malaria, filariasis, and arboviral diseases in some water resources development projects in Sri Lanka.[2]

Originally recommended by the WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM), the project was financed by the World Health Organization (WHO) and carried out under the joint coordination of the South Asia Cooperative Environment Program (SACEP) and the Sri Lankan Ministry of Health (MOH). Implementation was undertaken by the Anti-Malaria Campaign, Anti-Filariasis Campaign, and Medical Research Institute (Annex 1). The level of successful implementation of the study can serve, therefore, as an indicator of the efficacy and limitations of intersectoral/interinstitutional collaboration.

Study areas. Investigations were carried out in selected localities of the Mahaweli Development Project, System C, Zone 2 (Mahaweli C2), which is an area with a changing environment where irrigation water services and human settlements have been completed very recently (Map 1); and selected localities in Kirindi Oya/Lunugamwehera Project in southeastern Sri Lanka where settlements/ resettlements (Map 2) are in progress and irrigation water services have not yet started. The studies were conducted in each area in 2 phases of 21 days duration during the wet and dry periods.

Experimental procedure. Adult and larval mosquitoes were collected outdoors and inside "cadjan" (palm leaf) huts using human bait at night, hand collecting techniques, pyrethrum spray, cattle-baited net traps, bird/pig baited-traps, exit window traps, and larval sampling in both natural and man-made potential breeding habitats.

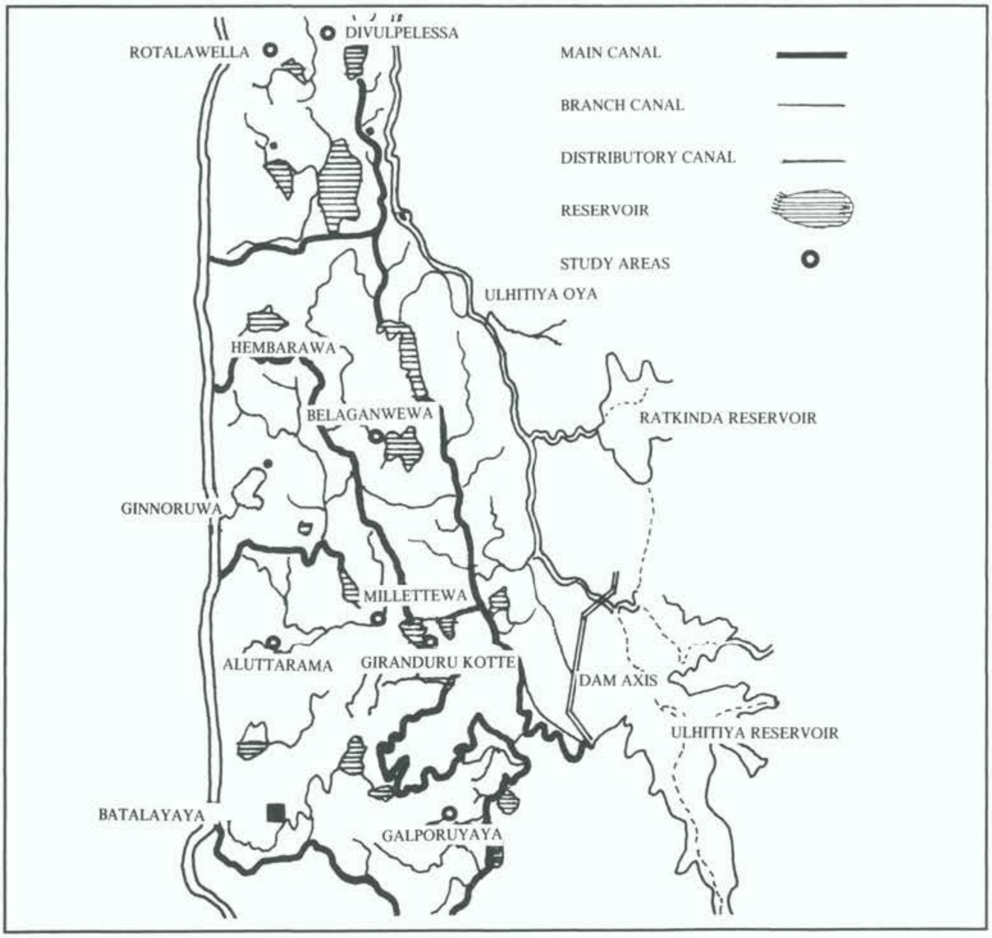
After species identification of all samples, the potential vectors of filariasis were dissected for microfilarial infections. Mosquitoes collected from pig-baited traps were used to isolate Japanese encephalitis (JE) virus.

Results and observations. This paper summarizes mainly the entomological findings in phase 1 (wet period). Laboratory processing of the material collected in phase 2 (dry period) is ongoing.

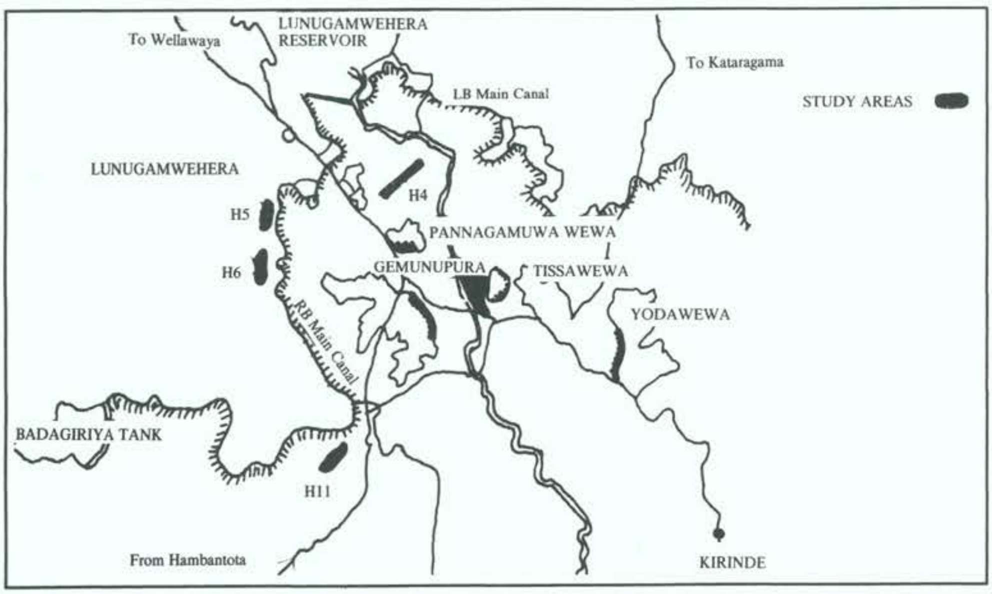
Forty-four species of mosquitoes, involving 13 species of anophelines and 31 of culicines were encountered in Mahaweli C2, and 11 anophelines and 27 culicines from the Lunugamwehera/Kirindi Oya sites. Most of the species were common to

[1]All the authors except W.M. Nanayakkara participated in Project 1; only P.R.J. Herath and W.M. Nanayakkara participated in Project 2.

[2]For detailed information on the arboviral component of this study, please refer to the article in these proceedings by T. Vitarana et al.



Map 1
Project 1 study areas in Mahaweli C2.



Map 2
Project 1 Study areas in Kirindi Oya.

both areas. *Culex hutchinsoni,* which has not been recorded previously in Sri Lanka[3], was reported from Mahaweli C2. Tables 1a and 1b show the mosquito fauna encountered in the two areas.

Table 1a. Mosquito fauna (Culicines) encountered in some of the representative areas of Mahaweli C2 and Kirindi Oya, 1985.

Species (Culicines)	Mahaweli System C	Kirindi Oya
Mimomyia (Mimomyia) hybrida	+	-
M. (Etorleptiomya) luzonensis	+	-
Coquillettidia (Coquillettidia) crassipes	+	-
Mansonia (Mansonoides) annulifera	+	+
M. (Mnd) indiana	+	-
M. (Mnd) uniformis	+	+
Aedes (Aedeomyia) catasticta	+	-
A. (mucidus) scataphagoides	+	+
A. (Finlaya) gubernatoris	+	+
A. (Christophersiomyia) thomsonii	+	-
A. (Stegomyia) aegypti	+	+
A. (Stg) albopictus	+	+
A. (Adimorphus) alboscutellatus	-	+
A. (Adm) jamesii	+	+
A. (Adm) pallidostriatus	+	+
A. (Adm) pipersalatus	+	+
A. (Adm) taeniorhynchoides	+	+
A. (Adm) vexans vexans	+	-
A. (Adm) vittatus	+	+
A. (Verrallina) butleri	+	-
A. (Neomelaniconion) lineatopennis	+	+
Armigeres (Armigeres) subalbatus	+	+
Culex (Lutzia) fuscanus	-	+
C. (Eumelanomyia) minutissimus	+	+
C. (Culiciomyia) nigropunctatus	+	+
C. (Cui) pallidothorax	-	+
C. (Culex) bitaeniorhynchus	+	+
C. (Cux) gelidus	+	+
C. (Cux) mimulus	-	+
C. (Cux) pseudo vishnui	+	+
C. (Cux) quinquefasciatus	+	+
C. (Cux) sitiens	-	+
C. (Cux) tritaeniorhynchus	+	+
C. (Cux) vishnui	+	+
C. (Cux) whitmorei	+	+
C. (Cux) hutchinsoni	+	-

Table 1b. Mosquito fauna encountered in some representative areas of the Mahaweli System and Kirindi Oya, 1985.

Species (Anopheline)	Mahaweli System C	B	H	Kirindi Oya
A. aconitus	-	-	+	-
A. annularis	+	+	+	+
A. barbirostris	+	+	+	+
A. culicifacies	+	+	+	+
A. jamesii	+	+	+	+
A. maculatus	+	+	+	+
A. nigerrimus	+	+	+	+
A. pallidus	+	+	+	+
A. peditaeniatus	+	-	-	-
A. ramsayi	+	-	-	-
A. subpictus	+	+	+	+
A. tesselatus	+	+	+	+
A. vagus	+	+	+	+
A. varuna	+	+	+	+

Among these are a number of species known to be vectors or potential vectors of malaria, filariasis, and arboviral diseases. Figure 1 compares the relative proportions of the different vectors and potential vectors from these areas.

Most of the anopheline species recorded are those which are commonly encountered in malarious areas of Sri Lanka. *A. culicifacies,* known to be the most important vector of human malaria in the country, was present in very small numbers in both areas. In addition, 10 species of anopheline *(A. annularis, A. barbirostria, A. jamesii, A. maculatus, A. nigerrimus, A. pallidus, A. subpictus, A. tessellatus, A. vagus* and *A. varuna)* which are considered potential vectors of human malaria in Sri Lanka occurred in both regions.[4] *A. nigerrimus* was the predominant anopheline species. Malaria is known to be endemic in both areas.

[3]Jayasekera, N. and R.V. Chelliah. 1981. An annotated checklist of mosquitoes of Sri Lanka" *MAB* (National Science Council) 8:1-16. Colombo, Sri Lanka.

[4]Herath, P.R.J., T. Abeywardena, and U.G.K. Padmalal. 1983. A study of the role of different indigenous Anopheline species in the transmission of human malaria in Sri Lanka, *Proc Sri Lanka Assoc Adv Sci:* 6 (abstract).

Figure 1. Relative proportions of different vectors and potential vectors in Mahaweli C (Jan/Feb) and Kirindi Oya (Feb/Mar), 1985.

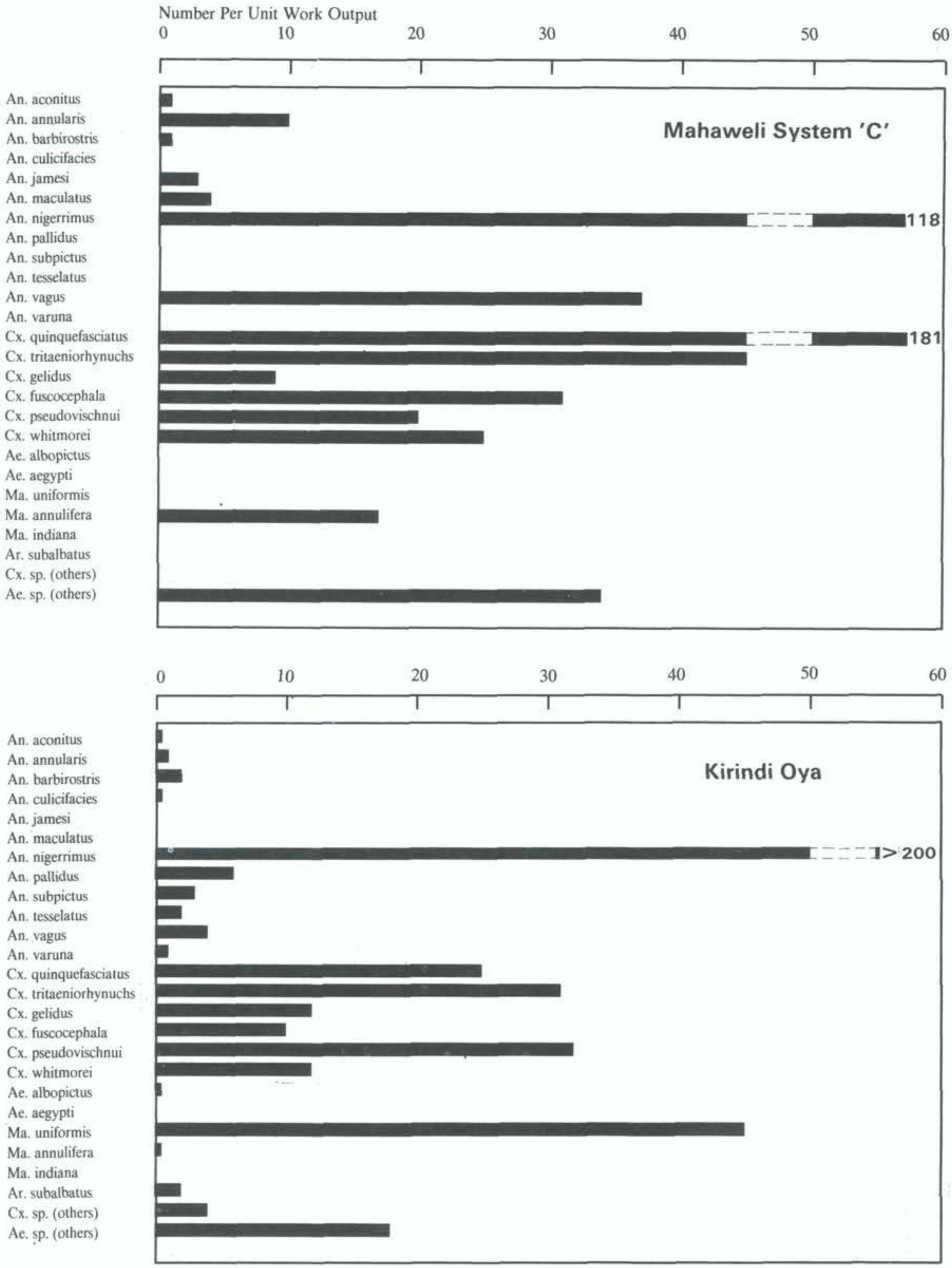


Table 2a. Major Breeding Places of mosquito vectors (established and potential vectors) of disease encountered in Mahaweli System C/Zone 2 February/March 1985.

Breeding places	Anopheline I-II Larvae	An (c) culicifacies	An (A) barbirostris	An (A) nigerrimus	An (A) peditaeniatus	An (c) aconitus	An (c) annularis	An (c) jamesi	An (c) kawari	An (c) maculatus	An (c) pallidus	An (c) subpictus	An (c) tesselatus	(c) varuna	An (c) vagus	Ae (Stg) aegypti	Ae (Stg) albopictus	Am (Arm) subalbatus	Cx (Cux) gelidus	Cu (Cux) fuscocephala	Cx (Cux quinquefasciatus	Cx (Cux) tritaeniorhynchus	Cx (Cux) pseudovishnui	Ma (Mnd) annulifera	Ma (Mnd) indiana	Ma (Mnd) uniformis
1. Rice fields	+			+										+					+	+		+				
2. Irrigation canal	+																									
3. Irrigation tank	+																									
4. Tank margin	+																									
5. Ground pool (rain water)	+	+		+				+											+	+		+	+			
6. Rock pools	+																									
7. Borrowpit	+																		+	+						
8. Catchpit																					+					
9. Damaged seal pit																					+					
10. Blocked drains																					+					
11. Earth drains																				+	+					
12. Marshy land	+			+																		+				
13. Cement tanks				+																						
14. Discarded recepticles																+	+	+			+					
15. Barrels																	+				+					
16. Tyres																	+				+					
17. Tree holes																	+	+								

Table 2b. Major Breeding Places of mosquito vectors (established and potential vectors) of disease encountered in Kirindi Oya February/March 1985.

Breeding Places	Anopheline	I-II Larvae	An (c) culicifacies	An (A) barbirostris	An (A) nigerrimus	An (A) peditaeniatus	An (c) aconitus	An (c) annularis	An (c) jamesi	An (c) kawari	An (c) maculatus	An (c) pallidus	An (c) subpictus	An (c) tesselatus	An (c) varuna	An (c) vagus	Ae (Stg) aegypti	Ae (Stg) albopictus	Am (Arm) subalbatus	Cx (Cux) gelidus	Cx (Cux) fuscocephala	Cx (Cux) quinquefasciatus	Cx (Cux) Tritaeniorhynchus	Cx (Cux) pseudovishnui	Ma (Mnd) annulifera	Ma (Mnd) indiana	Ma (Mnd) uniformis
1. Borrow pit		+	+	+				+	+			+	+		+	+					+						
2. Catch pit					+																						
3. Damaged seal pit																											
4. Blocked drains																		+			+	+	+				
5. Ground pool		+	+		+								+			+											
6. Rain water pools		+											+										+	+			
7. Rock pools		+	+	+	+	+							+														
8. Earth drains																						+					
9. Rice fields		+		+	+				+			+			+	+							+	+	+		
10. Marshy land		+			+																						
11. Cement tanks																		+				+					
12. Discarded recept																		+	+			+					
13. Barrels																		+									
14. Tyres																		+									
15. Irrigation canal		+			+										+	+							+	+			
16. Irrigation tank		+			+			+				+	+			+					+		+	+			
17. Tree holes																											
18. Sand pools		+			+										+		+										
19. Coconut shells		+																+	+								

The major breeding habitats of the non-anopheline species are shown in Tables 2a and 2b.

Culex quinquefasciatus, the established vector of bancroftian filariasis (due to *Wuchereria bancrofti)* in Sri Lanka, was the predominant mosquito species in the Mahaweli area and was also present in high numbers at Kirindi Oya. They were found to breed in a variety of man-made habitats which seem to be closely associated with rapid urbanzation. Although this type of filariasis is believed to be confined to a southwestern coastal endemic belt, it has been shown that the natural populations of *C. quinquefasciatus* in different parts of Sri Lanka are homogenous and are equally susceptible to *W. bancrofti* infections.[5] In Mahaweli C2, two microfilaria positive cases were found among the human population screened for *W. bancrofti* infections and an infection rate of 1.72% was detected in *C. quinquefasciatus* (Table 3).

in the area, the spread and stabilization of bancroftian filariasis in these situations can be expected. *Mansonia annulifera, M. uniformis,* and *M. indiana,* which have been incriminated previously as vectors of Brugia malayi, causing *brugian filariasis* in Sri Lanka, were also found in both areas.

C. tritaeniorhynchus, C. gelidus, C. fuscocephala, and *C. pseudovishnui,* which are established vectors of Japanese encephalitis (JE) in Southeast Asia, were recorded in both areas. *C. tritaeniorhynchus* was more prevalent in Mahaweli C2 than at Kirindi Oya, however, all species were found to be breeding in rice fields and ground pools in both study areas. Recent findings suggested that *C. tritaeniorhynchus* breeds predominantly in rice fields while C. gelidus is more commonly associated with ground pools and coconut husk pits.

Table 3. Filariasis: the status of the vector and disease in Mahaweli C2 and Kirindi Oya, 1985.

	Mahaweli System C2		Kirindi Oya
	Phase 1 Jan/Feb	Phase 2 Aug/Sep	Phase 1* Feb/Mar
No. of houses examined	261	232	86
Total *C. quing.* collected	3507	400	322
MH	38.3	5.1	14.9
No. dissected	1031	348	311
No. infected	-	6	-
percentage	-	1.72	-
Filarial larvae, range	0 - 0	1 - 10	0 - 0
Mean larvae/mosquito	-	6	-
Filaria positive persons detected in the area	2	*	1

*Results from phase 2 (Sep 1985) are being processed.

In this area, this is the first record of *W. bancrofti* infections in human and vector populations. Therefore, because *W. bancrofti* infections are present along with a high prevalence of the vector species

Aedes aegypti and *A. albopictus,* vectors of dengue and dengue haemorrhagic fever (DHF), were prevalent in Mahaweli C2, while only *A. albopictus* was recorded in Kirindi Oya (Table 4).

[5]Jayasekera, N., W.A. Samarawickrema, C.G. Jansen, and R.V. Chelliah. 1981. Filariasis in Sri Lanka: Crossing relations of natural populations of *Culex quinquefasciatus, J Nat Sci Coun Sri Lanka* 9(2):177-182. Samarawickrema, W.A., N. Jayasekera, R.V. Chelliah, and C.G. Jansen. 1981. Filariasis in Sri Lanka: Susceptibility of *Culex quinquefasciatus* to *W. bancrofti* (Cobbold) in Sri Lanka, *J Nat Sci Coun Sri Lanka* 9(2):171-176.

Table 4. Data on larval surveys for *Aedes aegypti* (A) *A. albopictus* (B) in Mahaweli C2 (Jan-Feb—and Kirindi Oya (Feb-Mar), 1985.

		Mahaweli C2	Kirindi Oya
Total no. of premises examined		850	600
Premises positive for breeding of	A	3	-
	B	122	93
Continer index	A	0.21	-
	B	11.22	17.19
Premises index	A	0.35	-
	B	14.35	15.50
Breteau index	A	0.35	-
	B	18.82	21.85

Three out of the 850 premises where water-holding containers were surveyed for Aedes breeding were positive for *A. aegypti* larvae in Mahaweli C2. Many of these containers were rubber tyres which had collected rain water. A. albopictus showed a Breteau index of 18.8% and 21.8% for Mahaweli and Kirindi Oya areas, respectively.

These observations, which show a relatively high level of species diversity, including many confirmed and potential vectors of several diseases of public health importance, could predict health hazards to settlers in these areas.

Annex 2 shows the intersectoral participation in the project by the different organizations. Collaboration in the project implementation was most effective among three institutions of the Ministry of Health (MOH).

Project 2

Project 2 is a bionomic study of indigenous anopheline species in the transmission of human malaria in Sri Lanka and, in particular, the factors related to vectorial capacities in different ecological, epidemiological, and geographical and seasonal situations in Sri Lanka.

Environmental changes which occur in major irrigation development projects appear to alter and possibly favor the transmission potential of disease vectors. This paper compares observations of vectorial capacities in malaria vectors from an area in the Mahaweli System which has undergone more than 10 years of environmental changes with two other areas which have been untouched by recent irrigation developments. All three areas possess the same climatic and geophysical characteristics, and historically have shown similar malaria transmission patterns. In addition, some preliminary data are presented on anopheline breeding in the Mahaweli Development Project area where the irrigation management practices are somewhat stabilized.

Financial support was received from the World Health Organization (WHO)/Tropical Diseases Research Programme (TDR) of the Scientific Working Group on FIELD/MAL and supplemented by the Anti-Malaria Campaign, Sri Lanka Ministry of Health. The study was conducted by the entomological field staff of the Anti-Malaria Campaign and a Graduate Research Assistant (Annex 3).

Study Areas. This report includes findings from three different environments within the north-central malaria endemic dry zone of Sri Lanka (Map 2). In all these areas tanks from the ancient irrigation system are still in use. These areas include:

1. Mahaweli System H, the Madatugama section of the Kekirawa Health Area, where major environmental changes have occurred following more than 10 years of settlements/resettlements, deforestation, and irrigation activities.

2. Wewala in the Dambulla Health Area with old settled villages and some environmental changes but not influenced by the recent irrigation activity of the Mahaweli Development Scheme.

3. A number of localities in Puttlam Health Area, also with settled villages but not affected by the Mahaweli irrigation network.

Experimental procedure. The anopheline species were studied and monitored for prevalence/abundance, indoor/outdoor human biting, resting behavior, animal (cattle) biting densities, longevity (parous rates), determination of human blood index (HBI), and exodus from houses. Standard collecting techniques were used, including the use of indoor/outdoor human-bait at night, outdoor hand techniques, pyrethrum spraying, window traps, cattle-baited "cadjan"/net traps, and blood meal for precipition testing, etc. The laboratory processing involved species identification, classification into blood digestion stages, dissection for parous rates, 24-hour mortality/ survival observations in window traps and insecticide susceptibility testing.

Owing to various constraints, particularly trained manpower, the duration and periods of work varied in the different areas. Madatugama was investigated for 21 days each month for 13 months in 1984-85, Wewala daily for 4 months in 1985, and localities in Puttlam Health Area for 7-14 days per month for 19 months during 1984-85.

Results and observations. The anopheline species (A. aconitus, A. annularis, A. barbirostris, A. culicifacies, A. jamesii, A. maculatus, A. nigerrimus, A. pallidus, A. subpictus, A. tesselatus, A. vagus, and *A. varuna)* generally found in malarious areas of Sri Lanka were recorded in all three sites. However, *A. culicifacies,* the predominant vector of human malaria, was recorded in very low numbers at Madatugama and Wewala. The overall prevalence of the different species from the three sites has not been compared.

Man-vector contact and longevity are two of the factors related to vectorial capacities and are generally considered important indicators following environmental changes due to irrigation development activities. Figure 2 compares these for the different anopheles species in relation to their overall prevalence in the respective areas.

Although all the anopheline species are known to be highly zoophilic, a degree of human biting was recorded similar to that in the rest of the country. There was no general increase in man-vector contact (human bait densities) following jungle clearing in development areas. It is possible that any imbalance in the man-animal ratio created in Mahaweli areas by deforestation and human settlements is counteracted by the high cattle population introduced to the areas, and to which mosquitoes are highly attracted.

Indoor resting sampling noted a somewhat greater population increase in the Madatugama area of the usually exophilic *A. vagus.* This could be expected to favor man-mosquito contact and needs to be monitored further. *A. culicifacies* and *A. subpictus* continued to be highly endophilic, as they are throughout Sri Lanka. Species longevity (expressed

Map 3. Map of Sri Lanka Showing the Representative areas Studied

Figure 2. Anopheline Prevalence, Human Biting Densities, Parous Rates and Indoor Resting Densities from the (3) Representative Areas.

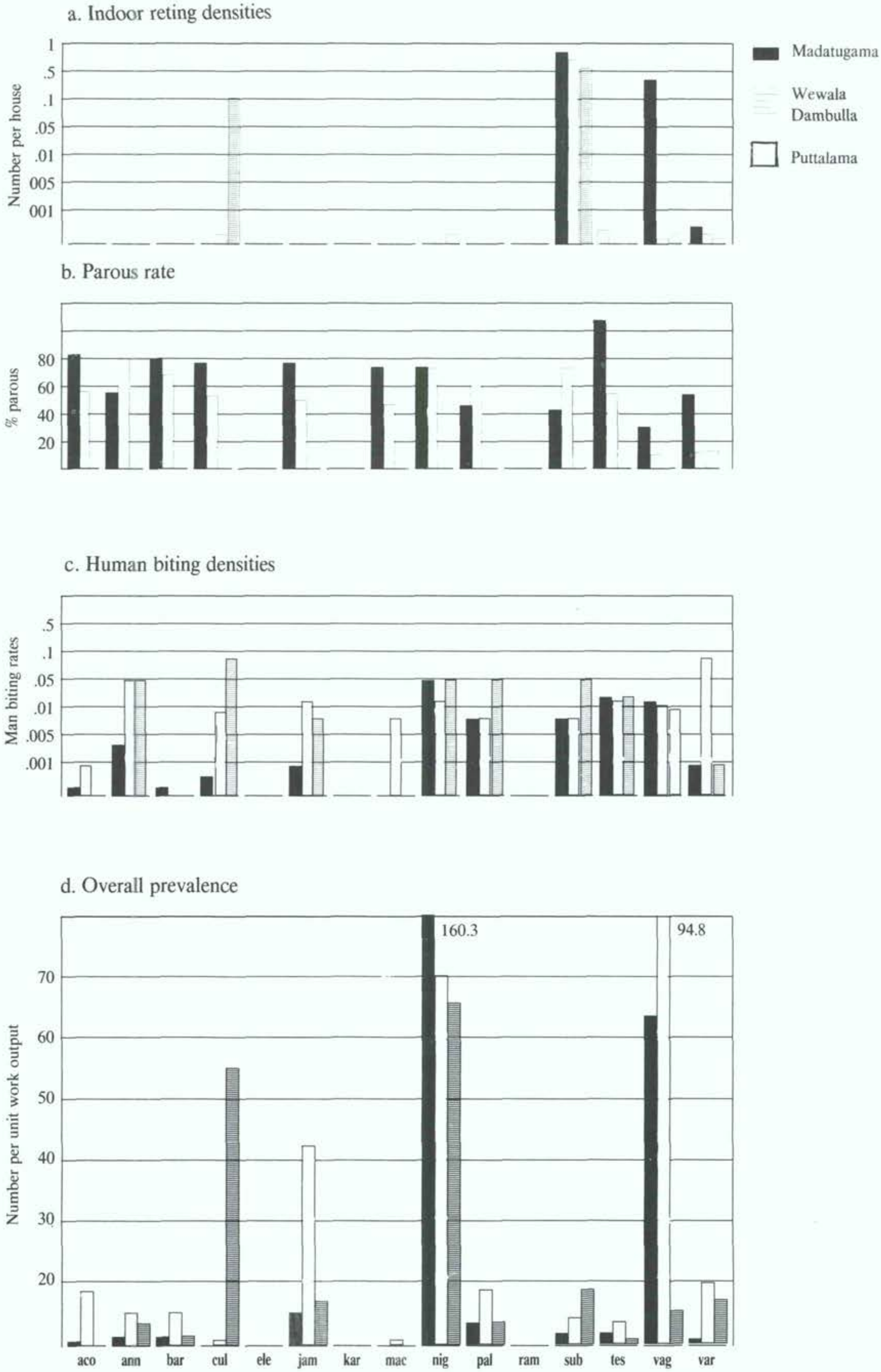


Table 5a. Data on larval sampling at Mahaweli H, May 1984-May 1985.

Breeding Places	No. of Spots Examined	No. of Spots Positives	No. of Dips Done	No. of Dips Positive	No. of Larvae Stages I-II	No. of Larvae Stages III-IV	An. acconitus	An. annularis	An. barbirostria	An. Jamesi	An. nigerrimus	An. pallidus	An. subpictus	An. tessellatus	An. vagus	An. varuna
							ANOPHELINE SPECIES									
Paddy field	7852	1373	76704	1327	1591	1506	22	05	71	29	1190	82	15	37	488	22
Dambulu Oya -margin	232	06	2576	06	08	08	-	-	-	-	05	-	-	-	03	
Dambulu Oya - sand pool	333	13	3231	40	43	47	-	-	-	-	27	03	-	-	10	01
Irrigation channel	1121	13	7682	01	22	56	-	-	-	-	22	-	-	-	34	-
Main canal	1220	16	18575	50	24	34	-	-	05	-	30	01	-	02	07	01
Distributing canal	1132	76	18354 +1591	138 +03	126	99	-	-	01	02	66	06	-	01	30	41
Distributing canal pool	107	14	1429	66	35	49	-	-	14	-	37	03	-	-	23	-
Field canal	1432	37	16438	90	70	110	12	01	01	04	68	01	-	02	08	28
Field canal pool	27	-	276	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock pool	236	35	2484	215	60	220	02	-	37	12	147	-	04	-	45	02
Earth well	59	-	1766	-	-	-	-	-	-	-	-	-	-	-	-	-
Stream	25	01	630	30	37	17	-	01	-	-	11	01	04	-	06	05
Rain water pool	1128	57	11092	127	209	173	09	-	01	05	103	25	-	-	76	02
Tyre track	51	03	409	18	03	21	-	-	-	-	01	-	03	-	19	-

Table 5b. Data on anopheline breeding in Madatugama (Mahaweli H), May 1984-May 1985.

	No. of spots	(% positive)	No. of dips	No. of larvae	(% of total)
Paddy field	7852	(17.5)	76704	3097	(67.8)
Dambulu Oya - margin	232	(2.6)	2576	14	(0.31)
- sand pool	333	(3.9)	3231	90	(2.0)
Sub-total	565	(3.4)	5807	104	(2.3)
Irrigation canal	1121	(1.2)	7682	78	(1.7)
Branch canal	1220	(1.3)	18575	58	(1.3)
Distributing canal	1132	(6.7)	19945	225	(4.9)
Dist canal pool	107	(13.0)	1429	84	(1.8)
Field canal	1432	(2.6)	16438	180	(3.9)
Field canal pool	27	(0)	276	0	(0)
Total canal system	5039	(3.1)	64345	625	(13.7)
Rock pool	236	(14.8)	2484	280	(6.1)
Earth well	59	(0)	1776	0	(0)
Stream	25	(4.0)	630	54	(1.2)
Rain water pool	1125	(5.1)	11092	382	(8.4)
Tyre track	51	(5.9)	409	24	(0.5)
TOTAL	14952	(11.0)	163247	4566	(100)

as parous rates) in Madatugama compared to areas not influenced by irrigation was higher for all species, except A. annularis, *A. pallidus,* and *A. subpictus.*

Preliminary data on larval breeding in Madatugama (Tables 5a and b) show the paddy fields to be a major breeding place for anopheline mosquitoes, and responsible for 67.8% of the total larvae sampled. By comparison, the irrigation canals recorded only 13.7%. This seems to suggest that the intermittent flushing resulting from the 7-day rotation for water releases in the area may to some extent control larval breeding in the irrigation canals. Dambulu Oya, the naturally occurring river in the area studied, recorded only 2.3% of the larvae, with no *A. culicifacies* recorded during the sampling period despite the fact that the river-and stream-beds are known to be highly preferred breeding habitats for this species. It appeared that the excess water channeled periodically through this river to a reservoir limited the pool formation and *A. culicifacies* breeding in the river beds, which is an advantage for malaria control efforts.

These observations suggest the need to investigate further the interaction of irrigation/agricultural practices, agricultural pesticide applications, and rainfall on mosquito reproduction in irrigation systems in order to identify environmental management approaches for vector control. Such studies seem most appropriate in irrigation systems where the environmental changes, settlements, irrigation water management, and agricultural practices are stabilized. This is now under consideration.

Annex 1. Staff who participated in the WHO/-PEEM study.

Dr M B Wickremasinghe	Entomologist, AMC
Dr K S P Kalpage	Entomologist, AFC
Mrs N Jayasekera	Entomologist, MRI
Dr U T Vitarana	Virologist, Director/MRI
Dr P R J Herath	Entomologist, AMC/MOH (Principal Investigator)
Mrs V Gunatilake	SACEP representative to WHO/PEEM study
F R Karandawela	Entomological Assistant (EA)
D R W Pathiranact	"
W M Weerasinghe	"
R M Bandara	"
N De Soyza	"
N W G Premaratne	"
G H Gamini	"
Sheik Shermath	"
G. Chandratillake	"
D.A.T. Bopearachchi	"
R.V. Chelliah	Technician
C.G. Jansen	"
K. Manoranjitham	"
S.K. Saranapala and field assistants, microscopists, mosquito collectors	

Annex 2. Intersectoral participation for the study on mosquito-borne disese in small scale water resources in Sri Lanka.

	Mini of Health	SACEP[b]	Mahaweli Authority	WHO[c]
Personnel				
professional	5	-	-	-
support	35	-	-	-
mgmt of funds, procurements	-	1	-	-
mgmt of transport	2	1	-	-
Equipment/Supplies	29%	-	-	71%
Transport/Vehicles	69.6	-	0.3	30.1
Staff salaries	96.5	3.5	-	-

[a] Anti-Malaria Campaign, Anti-Filariasis Campaign and Medical Research Institute; [b] South Asia Cooperative Environment Program; [c] World Health Organization.

Annex 3. Staff who participated in the study.

Dr P R J Herath	Entomologist/Anti-Malaria Campaign (AMC)
Mr W M Nanayakkara	Graduate Research Assistant/AMC
Mr D Sunil Premasiri	Entomological Assistant (EA)/AMC
Mr S A S Shermath	"
Mr D R W Pathiranac	"
Mr W M Weerasinghe	"
Mr K Dissanayaka	Field Assistant (FA)/AMC
Mr G Tillakaratne	"
Mr D Senaratne	"
Mr S H Faiser	"
Mr H N M Chandraratne	"
Mr H P Saranadasa	"
Mr A S Pathiranage	"
and mosquito collectors/AMC.	

Institutional Arrangements Between The Health and Irrigation Sectors: Present Status and Suggestions for Improvement

J. Bandaragoda[1]

Introduction

Water resources development in Sri Lanka dates to about 300 BC when an extensive network of irrigation tanks (reservoirs) was built in the northern and northeastern parts of the country. Many of these facilities, which had fallen into disuse and ruin, have been reconditioned and incorporated into new irrigation systems over the last century. Currently, these tanks irrigate around 360,000 hectares of land and efforts are continuing to expand this area.

The reservoir projects have been classified according to command area as major, medium, and minor-scale schemes. Generally, major irrigation schemes are defined as reservoirs having a command area of over 400 hectares.

In addition to reconditioning the ancient tank network, in recent times a number of multi-purpose water development projects have been undertaken. Among these are the Uda Walawe, Gal Oya, Inginimitiya, Kirindi Oya, Muthukandiya, and Mahaweli Ganga Development Projects. The principle objectives of these projects are to generate additional employment and increase agricultural and hydro-electric power production to meet the growing needs of the population.

Agencies Concerned with Irrigation Development in Sri Lanka

There are a number of agencies under different ministries, directly or indirectly concerned with the development of irrigation in the country.

Department of Irrigation. The Department presently functions under the Ministry of Lands and Land Development. It is responsible (with some exceptions) for irrigation and drainage development and for the operation and management of schemes over 80 hectares in extent. Department activities include identifying and formulating projects; investigating and preparing plans for developing river basins, feasibility studies, and designs for major irrigation schemes, lift irrigation works, and flood protection and drainage schemes; constructing major and minor irrigation works; maintaining existing irrigation works; and controling and issuing water.

Mahaweli Authority of Sri Lanka. The Ministry of Mahaweli Development was created to coordinate and implement the Mahaweli Development Project.

1. *Mahaweli Development Project.* The Mahaweli Ganga is the longest river in Sri Lanka and flows for its major part through the dry zone which has extensive land resources, and soils and climate suited to cultivation. Therefore, the development of this river is important for the future development of agriculture in Sri Lanka.

In 1968 a FAO/UNDP Master Plan for the development of the irrigation and hydro-power potential of the Mahaweli and its tributaries envisaged the development of 360,000 hectares of land in the Mahaweli and adjacent basins and the generation of 508 megawatts of hydro-electricity, with the potential for an additional 460 megawatts. Work on the Mahaweli Development Programme, which was originally scheduled for completion in 30 years, began in 1972.

[1] Executive Director, Mahaweli Economic Agency, Sri Lanka.

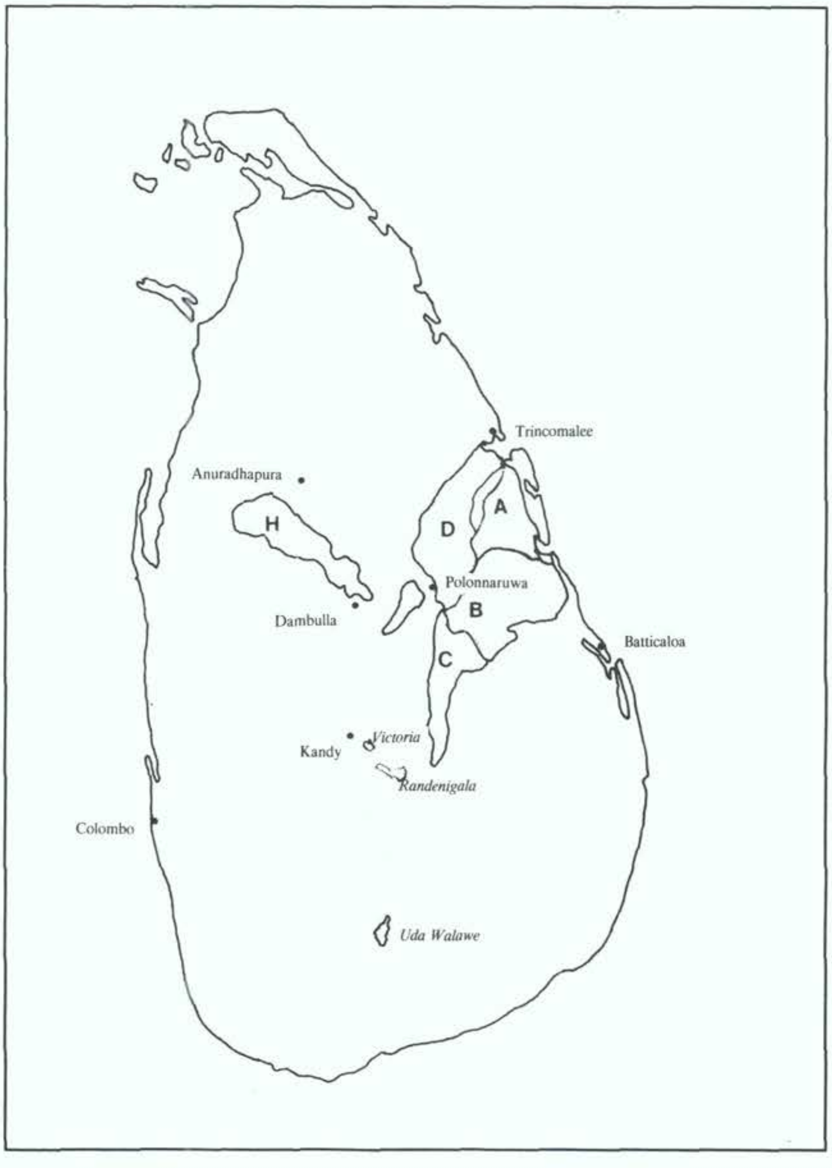


Figure 1.
Map showing Accelerated Mahaweli Program Area, Sri Lanka.

In 1977, the Government decided to implement a major portion of this program within a 6-year period, in order to derive the benefits of increased employment, power, and food production. The accelerated program involves the construction of five major multi-purpose reservoirs to provide 470 megawatts of power and irrigation to around 144,000 hectares of land in the irrigation systems designated "A - D," "G," and "H." Nearly one million people were to be settled under the project. A map of the Accelerated Mahaweli Development Project is provided in Figure 1.

1. *Administrative arrangements.* The Mahaweli Authority of Sri Lanka (MASL), created by an Act of Parliament in 1979, is responsible for planning and implementing the Mahaweli Development Project. A description of the functions of the MASL, as designated by the Mahaweli Authority Act Number 23 (1979), is provided in Annex 1. The MASL has the power to direct and control all agencies and institutions involved in the Mahaweli Development Programme. This high degree of autonomy invested in a single agency facilitates the decision-making considered essential for the implementing the development program.

The MASL has two subsidiary bodies: the Mahaweli Engineering Consultancy Agency (MECA), which is responsible for constructing irrigation and social infrastructure in the downstream settlement areas, and the Mahaweli Economic Agency (MEA). The MEA is responsible for settlement of new families and for the agricultural, social, and economic development in the downstream areas. This includes arrangements for delivering health care, as well as matters concerning the protection and management of the environment. The organizational structure of MEA at headquarters level is shown in Figure 2.

At project level (Figure 3), each project is headed by a Resident Project Manager (RPM) responsible for implementing and monitoring the settlement program. The RPM has the following specialists attached to his office: Land Officer, Water Management Engineer, Marketing Officer, Agricultural Officer, Community Development Officer, Accountant and Administrative Officer.

Each project area is further divided into blocks containing about 2,500 families and administered by a Block Manager representing the same functional areas as the RPM's staff. Finally, each block

Figure 2. Organizational structure of the Mahaweli Economic Authority (MEA) at headquarters level.

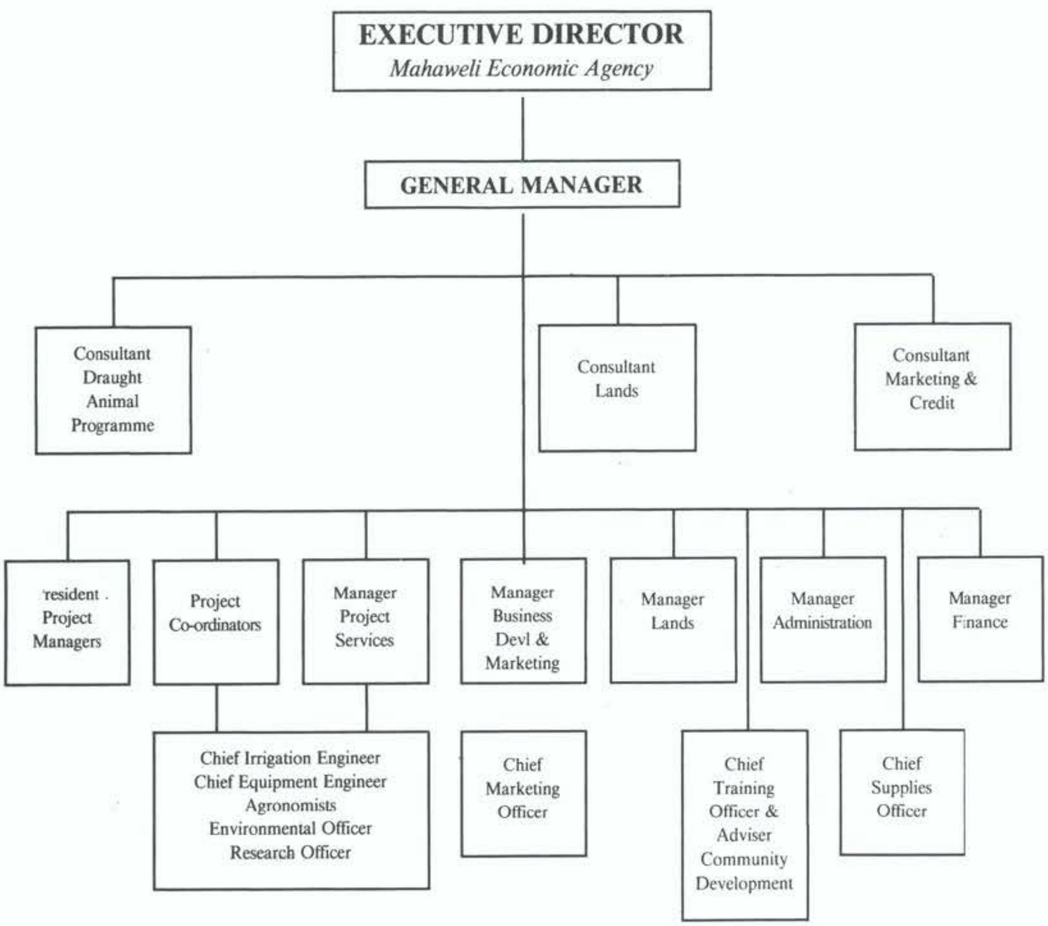
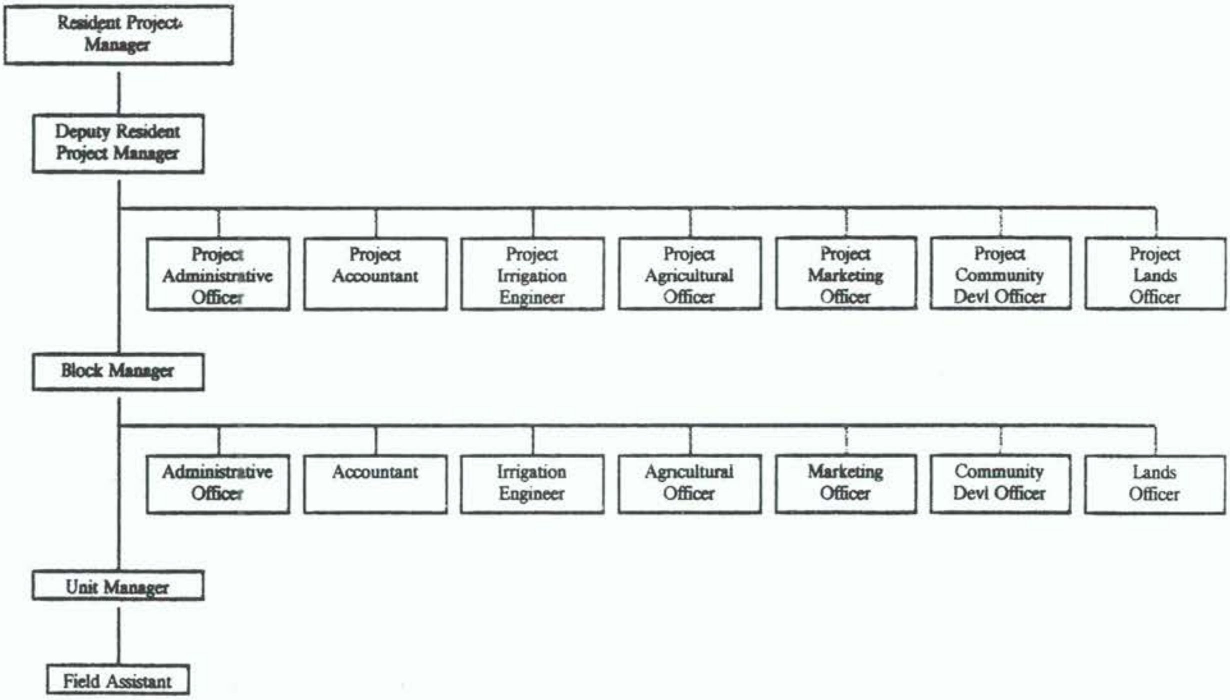


Figure 3. Organizational structure of the Mahaweli Economic Authority (MEA) at project level.



is divided into units of 200 - 250 families, headed by an Unit Manager supported by a Field Assistant. In the project areas, the MEA staff provides most services normally provided through other ministries.

Besides MECA and MEA, the MASL also funds the Central Engineering Consultancy Bureau (CECB), which is closely associated with the project. The CECB is the agency responsible for constructing the headworks at the Kotmale, Victoria, Maduru Oya, and Randenigala reservoir projects, and collaborates with the expatriate consultants at each of these projects.

3. *Other agencies.* A number of other agencies under different ministries are also involved, either directly or indirectly, in irrigation development. One of these, the Department of Agrarian Services under the Ministry of Agricultural Development and Research (MADR) is responsible for operation and maintenance of minor irrigation works falling under the command area of 80 hecatres. The Plan Implementation Division of the Ministry of Finance and Planning implements integrated district rural development programs under a decentralized budget.

Non-governmental and donor agencies provide additional institutional and financial support for the development of water resources in Sri Lanka.

Health Services

The health services provided throughout Sri Lanka are administered primarily by the Ministry of Health (MOH) through Regional Directors of Health Services. This Ministry provides both curative and preventive health services through a hierarchy of institutions which are organized regionally. Each region consists of a central provincial hospital surrounded by a network of district hospitals, each of which services a number of peripheral units.

The MOH consists of three fairly independent components: the medical or curative care services, public health services, and laboratory services. The vector control services of the MOH are offered through the Anti-Malaria Campaign (AMC) and Anti-Filariasis Campaign (AFC).

To conform with the objectives set by the "Health for All by the Year 2000" program designed in cooperation with the World Health Organization (WHO), the MOH is restructuring the health care delivery system. The objective of this program is to provide health care at the lowest possible management level. To accomplish this the Ministry recruits from the population one Volunteer Health Worker (VHW) per 50 families. The VHW will provide simple medical treatment, preventive treatment of malaria, and health education.

Institutionally, the restructured health care system consists of three tiers. The most peripheral unit of the system is the Gramodaya Health Center, where health care for a population of 3,000 will be provided by a Family Health Worker (FHW). First and second referral units will be at sub-divisional (for a population of 20,000) and divisional (for a population of 60,000) health centers, respectively. The existing district and provincial hospitals will provide higher-level referral services. The health care delivery system will also promote community participation for health and sanitation, as well as the gradual functional integration of curative and preventive care. However, insufficient numbers of trained health personnel and limited financial resources are constraints on the provision of adequate health services.

Institutional Arrangements Between Health and Irrigation Sectors in Mahaweli Areas

This paper focuses on the institutional arrangements between the health and irrigation sectors within the Mahaweli settlement areas.

Health care services in the Mahaweli area, as elsewhere in Sri Lanka, are administered by the MOH. However, the MEA provides additional resources with assistance offered by donor agencies. The intention is to strengthen the health services being provided through the national programs. The contribution made by MEA to the health program is largely through infrastructure. Additional health personnel, drugs and programs for community development, and provision of some public health care services also form part of the MEA contribution.

The MOH appoints a Senior Medical Officer to be the liaison between the MEA and MECA, but collaboration is primarily on matters pertaining to health infrastructure and assignment of health personnel. In planning the health infrastructure, the MEA consults the MOH so that plans conform to the national health system. The MOH is also consulted on selection of the sites for hospitals and health centers, as well as on the type and number of buildings to be constructed. A technical subcommittee of MASL, chaired by its Executive Director, reviews and monitors policy issues. A technical subcommittee exists also at the project level.

There is a time lag between the arrival of settlers in the new settlement areas and the full operation of the health institutions. This applies to both infrastructure and the necessary medical staff. Until the health institutions are fully operational, the MEA has appointed Project Medical Officers (PMO) to meet the urgent health needs of the new settlers. These officers provide preventive and curative health care services through a number of mobile clinics. Polyclinics are also conducted in a similar way by the MOH.

The Anti-Malaria Campaign moves into the development area at the commencement of settlement. It undertakes the prevention and treatment of malaria including spraying, blood-filming, surveillance, and providing prophylactics for non-immune new settlers. However, anti-malaria drugs are issued simultaneously and independently by the Mahaweli PMOs, Health Department officers, and AMC personnel.

Therefore, in the Mahaweli areas, health services to the settlers are being provided by the MOH, with only supportive assistance from the MEA. However, the MEA has a commitment to provide the following primary care services: 1) health education, 2) adequate nutrition and, 3) the supply of safe water and proper sanitation. Most of these programs are supported by donor institutions.

The MEA promotes health education through the training and support of Volunteer Health Workers (VHW). The Health Education Bureau and local health personnel of the MOH is responsible for training the VHWs. The Health Education Bureau also provides training to MEA staff. The education program is tailored primarily to familiarize settler families with the basic sanitary and hygienic requirements, and the practices necessary to meet such requirements.

The MEA is also responsible, through its Community Development Officers, for the nutrition education program in the Mahaweli areas. The Department of Community Medicine, University of Peradeniya, provides the technical training to MEA officers. The MEA also runs Home Development Centers at project levels where, in addition to special courses given to young women, information on health and sanitation is available.

The program to provide safe drinking water to settlers is carried out by MEA with donor assistance. In the newer settlement areas MEA provides subsidies for constructing one well per household. Under the sanitation program, households are provided with floor-plates and subsidies for digging latrine pits and erecting superstructures. Through the education program, MEA encourages settlers to use these facilities.

The MASL has established a Technical Subcommittee on Environment, chaired by its Director General and made up of representatives of the following governmental and non-governmental agencies and organizations: the Agencies of Forest Conservation, Wildlife, Agriculture, Fisheries, Health, Irrigation, Natural Resources, Energy and Science Authority, Central Environmental Authority, and the universities. This sub-committee, which meets monthly, is responsible for advising the MASL on environmental problems and assisting in the implementation of environmental programs in the Mahaweli areas.

Conclusions and Suggestions for Improvement

1. Present arrangements between the health sector and the irrigation sector (MASL) are primarily geared to provide curative and preventive health services. The preventive health services which are available in the downstream areas are inadequate in that they are mainly concerned with immunization and prophylactic treatment, with insufficient attention given to incorporating environmental and health safeguards for disease control, particularly for vector-borne diseases. It is essential that safeguards be incorporated at all stages of the project (planning, implementation, and operation), especially for vector control. Some of the environmental safeguards which need to be addressed are: designing irrigation systems to high flow velocities, lining canals to prevent pooling, locating settlements away from waterways to limit the contact of mosquitoes with humans, and managing irrigation systems for proper operation and water use. In this respect, the MOH should be involved from the design stage onwards. In 1984, the government made environmental impact assessments (EIA) a mandatory requirement for development projects. However, technical expertise must be strengthened in the project-approving ministries to guarantee that adequate environmental safeguards related to health are included in the EIA. Legislation is also being drafted by the Central Environmental Authority under the National Environment Act of 1980 to ensure that development agencies incorporate environmental safeguards at all stages of project implementation and operation in accordance with the EIA recommendation. In the future, Mahaweli systems such as A and D and the right bank of Maduru Oya could benefit from incorporating environmental safeguards for vector-disease control through better interaction between the sectors concerned.

2. Better coordination is necessary for effective delivery of health services to areas that are already operational. The present technical sub-committee of the MEA should meet regularly to review policy, monitor its implementation and operation, and evaluate the effectiveness of inputs. Constraints and problems could be identified so that early corrective mea-sures could be implemented. The coordinating committee should be multi-disciplinary in nature consisting of health and community development personnel, water management engineers, agronomists, sociologists, economists, managers of MEA, design and construction engineers of MECA, health officers (including the vertical vector-disease control

programs such as AMC and AFC of the MOH), and donor groups supporting the health programs.

3. At present, the direct coordination of vector-disease control programs is ad hoc in the Mahaweli program. In view of the importance of environmental management for vector control, it is critical that a functional committee be established at project level to coordinate the implementation of control measures. This committee should include regional members from the vector control programs (AMS and AFC), as well as from MEA, MOH, and MECA.

4. Increased efforts should be directed to acquiring more knowledge about the vector control effect if environmental management is to become effective in vector control. It is suggested that the vector control campaigns, along with the MEA and MECA, identify immediate study or research needs for the area. These studies should be carried out jointly by the irrigation and health sector. This will result in a much better understanding between the different sectors and make implementation of management measures more effective.

5. Because the irrigation sector lacks knowledge and expertise in the health disciplines and trained manpower is a constraint, it is important that the irrigation sector personnel receive training on aspects of health and environmental management measures. The need for education and training on health and environmental issues at all staff levels must be recognized. The MOH should consider developing a suitable training package for irrigation personnel, including guidelines for vector control by environmental management. Similarly, health personnel should understand the water management programs being operated by the irrigation sector so that the development of effective control measures become possible. Environmental management at field level is of vital importance, and the present VHW system should be strengthened to provide a system for transfer of vector control information to the farmer.

Annex 1

The powers and functions of the Mahaweli Authority of Sri Lanka as designated by Mahaweli Act 23 (1979) in, or in relation to, any Special Area are:

a) to plan and implement the Mahaweli Ganga Development Scheme including the construction and operation of reservoirs, irrigation distribution system and installations for the generation and supply of electrical energy;

b) to foster and secure the full and integrated development of any Special Area;

c) to optimize agricultural productivity and employment potential and to generate and secure economic and agricultural development within any Special Area;

d) to conserve and maintain the physical environment within any Special Area;

e) to further the general welfare and cultural progress of the community within any Special Area and to administer the affairs of such area;

f) to promote and secure the participation of private capital, both internal and external, in the economic and agricultural development of any Special Area;

g) to promote and secure the cooperation of government departments, state institutions, local authorities, public corporations and other persons, whether private or public, in the planning and implementation of the Mahaweli Ganga Development Scheme and in the development of any Special Area.

Special Area: The Act provides that the Minister in charge of the Mahaweli Development Programme could declare, with Presidential approval, any area which could be developed with the water resources of the Mahaweli Ganga, or any other major river, as a "Special Area," after which the Authority could exercise all, or any, of its powers, duties and functions in this area.

Environmental and Water Management for Vector Control[1]

Joseph K. Shisler[2]

The increased concern about vector populations and disease associated with the development of water management projects, coupled with vector resistance to pesticides and failure to eradicate disease, has revived interest in environmental management methods for the control of vector populations. Environmental management for vector control has been defined as the planning, organizing, carrying out, and monitoring of activities for modifying and/or manipulating environmental factors or their interaction with man, with a view to preventing or minimizing vector propagation and reducing man-vector-pathogen contact.[3] Historically, environmental management methods were a major component of vector control, but were replaced by the use of pesticides in the 1940's. Today, many of these methods are lost, along with their documented impact upon vector populations and disease.

Integrated Vector Control

An integrated vector control program is defined as the utilization of all appropriate technological and management techniques to bring about an effective degree of vector suppression in a cost-effective manner.[4] Such a program should involve a continuous process of education, re-education, training, and re-training of program directors because of the increased diversity of methods and equipment. Environmental techniques and methods, accompanied by effective educational and training programs, must be based on data from currently successful programs. Organizations and agencies should critically review these techniques and methods before they are accepted and implemented.

A knowledge of the epidemiology of the disease and the ecology and biology of its vector is essential for the implementation of effective environmental management techniques. Today, as we discuss malaria in Sri Lanka - and especially how malaria is related to irrigation and the Mahaweli Project - a major consideration must be the implementation of vector control activities and education and training programs for personnel involved in water management. The development of education and training programs is complex because it must take into account the differences in personnel backgrounds, applicable data, and availability of educational and training materials.

For the past four years I have been a member of a team teaching a course on stormwater management facilities for engineers. This is part of my responsibility in managing the section on environmental and mosquito problems associated with stormwater facility development. Stormwater management became an issue when mosquito control personnel in New Jersey observed an increase in the number of mosquito problems associated with stormwater facilities. Research showed that problems were created by the design, construction, and

[1]New Jersey Agricultural Experiment Station publication D-40502-01-85.

[2]Mosquito Research and Control, Cook College-Rutgers University, New Brunswick, NJ, USA.

[3]World Health Organization. 1981. *Manual on Environmental Management for Mosquito Control with Special Emphasis on Malaria Vectors.* Geneva: WHO Publication No. 66. 283p.

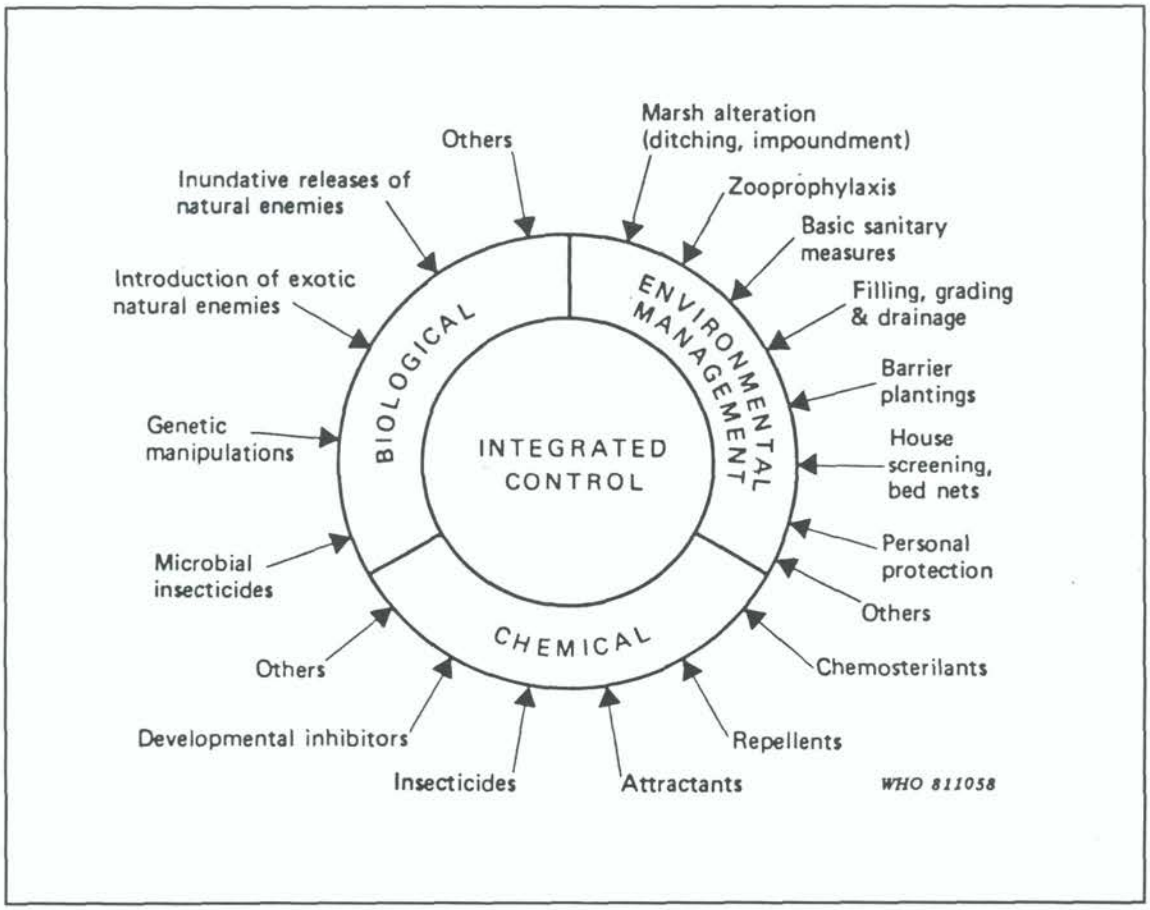
[4]Mather, T.H. and T.T. That. 1984. *Environmental Management for Vector Control in Rice Fields.* Rome: FAO. 152p. World Health Organization. 1983. *Integrated Vector Control.* Seventh Report of the WHO Expert Committee on Vector Biology and Control, Technical Report Series No. 688, 72.

maintenance of these facilities. The data generated by this research are the basis for my contribution to the course. The course by objective is to instruct engineers about the potential mosquito problems and their prevention through proper design and construction. The attending engineers have developed, through several years of experience, their own methods of handling problems associated with stormwater management. They are usually involved only in the design phase of projects, while other engineers, perhaps from another firm, oversee the construction, but none of these would be involved in maintaining the project.

A parallel can be drawn with water development projects worldwide, where changes occur in personnel and firms as the project moves from conception to operation. Training of all personnel involved in a project must be a major component in the implementation of integrated vector control programs. A major constraint on the development of education and training programs is the lack of available data, particularly in environmental management. These programs must be based on case studies and "hard" data to support the selection of environmental management techniques. The educational and training materials should be group-specific, including publication in the appropriate language.

An examination of Figure 1 reveals that education is not included. Note should be taken of the

Figure 1. Diagram of the components (environmental management, chemical, biological) and their potential constituent methods to be considered in an "integrated control" approach to mosquito control.[5]



[5]Axtell, R.C. 1979. Principles of integrated pest management (IPM) in relation to mosquito control, *Mosquito News* 39:709-718.

research carried out on the various components of this diagram. Recent literature includes very few studies which deal with environmental management methods. Most research on environmental management is carried out in the United States and is done by the individual mosquito abatement districts or states involved in mosquito control. There appears to be no federally-funded research projects or positions in environmental management for mosquito control. Several short-term and relatively small projects have been funded through Coastal Zone Management funds or with grants from individual federal departments. Even the well-planned and classic multidisciplinary Riceland Mosquito Management Program in the southern USA[6] did not include a significant environmental management component.

Since research on environmental management methods cannot be carried out over the short term, it is difficult to obtain information appropriate for publication. A year's research on a pesticide can generate a number of publications; in environmental management one year of research will produce only a preliminary study which must be followed by the application of the environmental management method. Several additional years will be required to determine the effects of the application. This lengthy process creates problems of funding and professional advancement for researchers in this discipline.

Evidence of increasing interest in environmental management and vector control is the formation of the WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM).

The 1984 paper on vector control in rice fields by Mather and That (see footnote 4) proposed five criteria for environmental management methods which should be applicable to any type of water management project. Methods must be:

1. known to be effective against the identified problem vector(s);

2. be socially acceptable;

3. cost effective when compared with other feasible methods;

4. economically sustainable by the community at some agreed level of responsibility; and,

5. compatible with local crop production techniques.

In using these criteria, it is important that databases be developed, through literature review and research, to implement effective integrated vector control programs in water development projects.

The International Irrigation Management Institute (IIMI)

IIMI's objectives offer ideal opportunities to implement irrigation schemes which could serve as models, and to develop the database and educational strategies so urgently needed. IIMI has three research programs:

Rehabilitation of irrigation projects. A major objective in future irrigation development will be the rehabilitation of older irrigation systems. The opportunity to study the disease and its vectors in a functioning system make these old systems ideal research environments. Their rehabilitation will provide the opportunity to implement vector control methods. This kind of work has been done at various locations around the world but it appears that a collaborative study by vector control specialists and engineers has occurred only once, at the Tennessee Valley Authority (TVA).

Vector habitats do not occur throughout the entire irrigation system nor are vectors found during all seasons. Therefore, detailed studies on where and when the vectors appear, and why they are not present in some areas of the system, will develop a database that will allow the rehabilitation engineers to eliminate vector habitats. Thus, a close working relationship between vector control specialists and engineers should be required on all projects.

[6]Olson, J.K. et al. 1981-1983. *Project Summaries.* Washington, DC: Riceland Mosquito Management Program, Office of Research and Development, US Environmental Protection Agency.

Main system management. Main system management usually deals with water control throughout the system. Here, the application of environmental management methods for vector control becomes more of an administrative duty. The most common of these administrative duties would be selecting fields for intermittent irrigation, selecting crops and determining rotations, and assigning committees and personnel duties. An awareness by the administration personnel of the impact of certain management programs upon vector populations and disease transmission could eliminate future problems. Again, the need is for a working relationship between vector control specialists and administration personnel to determine the selection and timing of environmental management programs which can be implemented without changing the objectives or the general management of the irrigation scheme.

Small-scale village-operated irrigation systems. The small-scale or community-run irrigation system offers an excellent opportunity to implement certain environmental management programs in conjunction with education and training. Because of the diversity of systems, locations, and crops, it will be difficult to develop comprehensive techniques, but certain generalizations can be applied and details concerning the vector biology of individual species or selected areas can be obtained from a database.

The education of farmers concerning integrating environmental management techniques into their work scheme must be related to the objectives of their irrigation system. If significant changes in these objectives are required in order to implement environmental management methods, the control program will fail. The major challenge is to incorporate integrated vector control strategies into farmer education programs worldwide.

The importance of an integrated approach was demonstrated recently in an anti-malaria program in Zaire. Field inspections showed that fish ponds played a predominant role in the propagation of vector species.[7] These have been constructed throughout the area by various organizations for developing protein resources. Apparently it was assumed that the fish would eat the mosquito larvae. However, not all species of fish eat mosquitoes, nor do all fish species penetrate the surface vegetation to feed upon mosquito larvae. A simple component of vector control in the education system for developing aquaculture could have prevented this problem.

Conclusion

Important initial steps are being taken by PEEM to develop collaborative centers in the fields of irrigation and rice culture research. This should be followed by establishing a working relationship between the vector control and irrigation specialists to develop both the databases and the educational and training materials needed in developing and operating future irrigation schemes.

Research should address the major problems associated with the design, construction, management, and maintenance of irrigation systems. The data and results, translated into the appropriate language, must be made available to the various organizations and personnel involved with irrigation systems.

[7] Brooks, G.D. and J.K. Shisler. 1980. *The feasibility of, and recommendations for, anti-larval measures against vector Anophelines in Zaire.* Washington, DC: American Public Health Association. 28p. Shisler, J.K. and G.D. Brooks. 1981. The application of water management methods for controlling vector-mosquito populations in Tropical Africa, *Proceedings of New Jersey Mosquito Control Association* 68:32-36.

Irrigation and Vector-Borne Diseases: A Case Study in Sri Lanka

J. J. Speelman, and G. M. van den Top[1]

Introduction

During eight months of field work in the Mahaweli Program, System C, Zone 2 during Maha season 1984/85, technical irrigation features associated with vector habitat creation were studied. These include: 1) Irrigation water supply design criteria for rice cultivation; 2) problems of excess water when constructing, operating, and maintaining the irrigation/drainage canal network; 3) methods of identifying potential vector breeding habitats in the project area; and 4) environmental management measures.

The Study Area

System C is located on the right bank of the Mahaweli River. It comprises 63,000 hectares (Fig. 1).

The area's topography is sloping and irregular, which, combined with soils and other factors, limits the area of land that is suitable for irrigation.

Suitable areas for irrigation are the valley bottoms or small catchments, whose soils are Low Humic Gleys (LHG). These gradually change uphill, at slopes up to 3%, to imperfectly drained Red Brown Earth (RBE) soils, which are also suitable for irrigation.[2] The ridges and steepest slopes (4-6%) consist of well-drained RBE soils or granite rock knobs, which are not suitable for irrigation. This means that only about 26,000 hectares (42%) of System C is suitable for irrigation. Table 1 shows the land use.

Table 1. Land use in Mahaweli, System C.

Category	Hectares	%
Turnout - paddies & residual land	28,102	45
(Irrigable)	26,041	42
Settlement townships & hamlets	11,113	17
Forest	7,711	12
Grazing	4,816	8
Other (rocks, etc.)	2,536	4
Total	28,102	100

For administrative purposes, System C has been divided into zones, of which Zone 2 was the first to be developed. During the wet season of 1984/85, the full extent of Zone 2's irrigable land (4,000 hectares) was under irrigation for the first time. The crop was rice.

Zone 2 is situated in the intermediate climatic zone, which forms the transition between the Wet and Dry Zones. The mean yearly rainfall is 21 centimeters, most of which falls in the wet season (or Maha) during the Northeast Monsoon from October to April. The dry season (or Yala) coincides with the Southeast Monsoon from May to September.

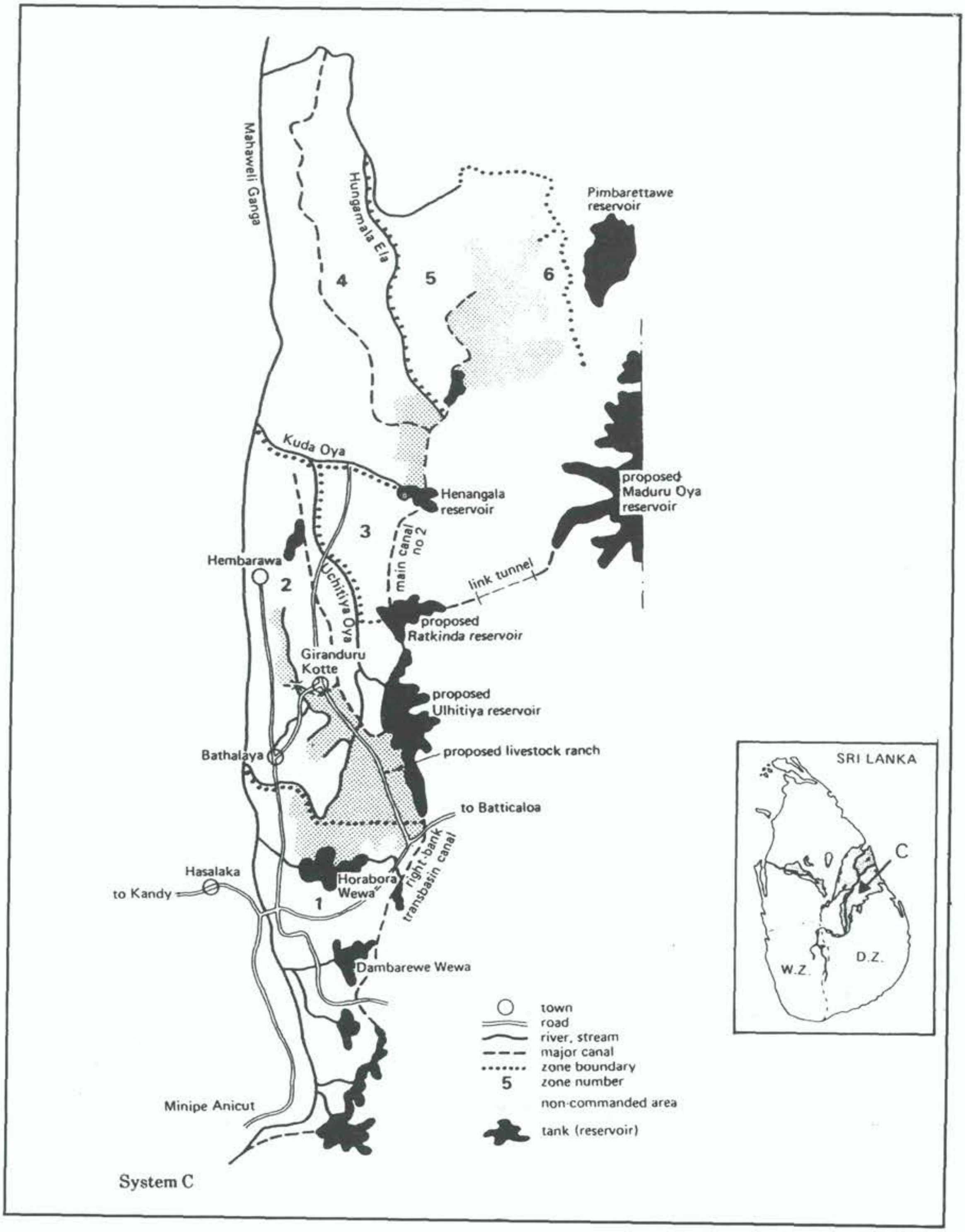
The headworks in the Mahaweli River provide the necessary water storage and flow regulation to safeguard the water supply to System C's main reservoir, the Ulhitya, throughout the year.

System C's irrigation system consists of a main canal taking off from Ulhitya, branch canals discharging into various buffer reservoirs, and distribu-

[1]With assistance from Ir. J. de Wolf and Dr. J.M.V. Oomen, International Institute for Land Reclamation and Improvement (ILRI), Wageningen, Netherlands, and Ir. K. Roscher, University of Agriculture, Wageningen.

[2]Hunting Technical Services. 1980. *Feasibility Study, System C, Mahaweli Project.* Borehamwood, United Kingdom.

Figure 1. The Accelerated Mahaweli Development Project, System C, 1983.



utary channels taking off from these reservoirs and conveying water to the minor irrigation units, or turnouts. Every turnout has one field channel running downslope and serving between 5 and 20 farmers, each owning one hectare allotments of paddy lowland. In addition, each settler family gets a 0.5 hectare homestead on which to cultivate other food crops.

Public Health and Vector-Borne Diseases in System C

The major public health problems being combatted by the Sri Lankan authorities are malaria, gastro-enteritis, accidents, dysentery, and anemia.[3] In System C, the most prevalent ailments are those related to poor hygiene and sub-standard living conditions: malnutrition, water-washed diseases, respiratory diseases, and vector-borne diseases (Table 2).

Table 2. Some data on public health in System C, 1983-84.

Diseases treated	1983 (%)	1984 (%)
Respiratory infections	20.6	21.3
Worm infestations	16.8	16.0
Skin infections	13.6	12.7
Malnutrition	12.2	11.6
Bowel infections	11.5	14.5
Genito-urinary infections	9.0	6.8
Accidents	6.9	5.4
Clinically detected malaria	4.4	8.0
Cardio-vascular conditions	0.5	0.4
Filarial infections	0.3	0.4
Other illnesses	4.2	2.9
Total cases treated	37,551	46,535

The most serious vector-borne diseases are malaria, filariasis, dengue, and Japanese B-encephalitis.

Malaria. Country-wide figures show an average of 7% of the examined blood films to contain malaria parasites, with incidences of 12% in 1983 and 17% in 1984. In Sri Lanka, the sole proven vector of malaria is *Anopheles culcifacies.* Mosquitoes of this species prefer a breeding place in full sunlight, clear water, and on a sandy or rocky bed. Six other *Anopheles* species present in Sri Lanka are confirmed malaria vectors in neighboring countries. Research data point to potential danger from these -and five other anopheline species.[4]

Filariasis. Bancroftian filariasis is endemic in the densely populated southwestern coastal strip. Recent independent research[5] revealed incidences of 5% transmission of this disease in the endemic belt, as well as recorded incidences outside the belt. The vector is *Culex quinquefasciatus,* which prefers a shady and organically polluted breeding place. Brugian filariasis is thought to have been eradicated from the island during the first intensive Anti-Filariasis Campaigns, when the removal of water plants associated with the breeding place of its vectors, *Mansonia spp.,* proved to be a successful measure.

Dengue and Japanese B-encephalitis (JE). Records of the prevalence of these diseases are not available, but serological evidence suggests that dengue fever is associated with densely populated human habitation. Its main vector, *Aedes aegypti,* prefers a breeding habitat in man-made containers: old tires, tin cans, etc.

The main vector for JE is *Culex tritaeniorhyncus,* which breeds in rice fields. Pigs apparently play a role in the epidemiology of the disease.[6]

Health Care

Three independently operating organizations provide health care in System C: the Mahaweli Authority, the Ministry of Health, and the Anti-Malaria Campaign. Each contributes to community health services, hygiene education, and sanitary provisions around settler's homes.

[3]Ministry of Health. 1983. *Annual Health Bulletin.* Colombo.

[4]Anti-malaria Campaign. *Second Independent Assessment of the Intensive Malaria Control Programme.* Colombo: Ministry of Health.

[5]Jayasekera, N. and K.S.P. Kalpage. 1986. *Entomological and Parasitological Field Study on the Transmission of Bancroftian Filariasis in Sri Lanka.* Colombo: Medical Research Institute (in preparation).

Measures included in the present program of controlling vector-borne diseases are: indoor insecticide spraying and medical treatment of recognized cases, particularly of malaria. In the endemic belt, the Anti-Filariasis Campaign regularly sprays larvicides on the potential breeding places of the filariasis vector. For the following reasons, however, there is an urgent need for a more diversified, and therefore less vulnerable, long-term control of vector-borne diseases:

1. The increased human mobility in and out of the Project area is promoting the transmission of vector-borne diseases.[7] The intensity of transmission is likely to change with the changing microclimate, vegetation, animal population, number of waterways, and other environmental changes now being introduced by development activities.[8]

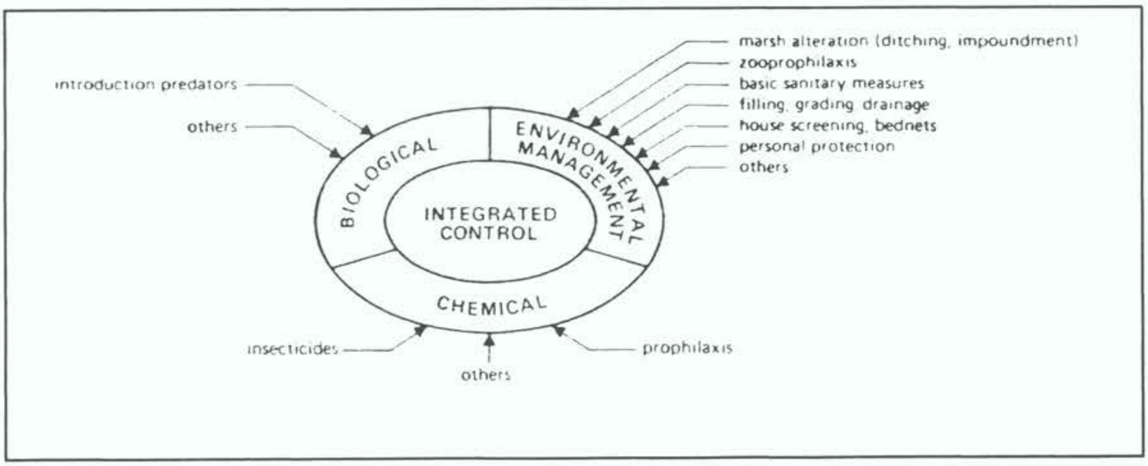
2. Neither the Anti-Malaria nor the Anti-Filariasis Campaigns have sufficient funds or manpower to intensify their activities in the Mahaweli Project areas.[9]

3. The present vector control by spraying is not entirely effective because: a) An estimated 40%[10] of the System C population are displaying an increasing unwillingness to have their houses sprayed because of the unpleasant smell and the fear that it has an adverse effect on health; and b) pools used by humans and animals must be excluded from spraying because of the risk of the pools becoming poisoned.

4. The heavy reliance on chemicals to control vector-borne diseases makes the Campaigns vulnerable because of the pace at which vector mosquitoes develop resistance to the chemicals.[11]

Figure 2 shows the concept on an integrated control that has been developed to meet the need for more diversified approaches to vector control. This

Figure 2. Diagram of the components to be considered in an "Integrated Control" approach to mosquito control[a/]



[a/] Axtell, R. C. 1979. Principles of Integrated Pest Management (IPM) in relation to mosquito control, *Mosquito News* 39:709-718.

[7] Fernando, M. (ed.). 1984. *Human Population Movements and their Impact on Tropical Disease Transmission and Control in Sri Lanka.* Proceedings of a Workshop, University of Peradeniya, Faculty of Medicine; the World Bank; and the World Health Organization (WHO).

[8] TAMS (Tippets, Abbett, McCarthy, and Stratton). 1980. *Environmental Assessment Accelerated Mahaweli Development Programme* (for Ministry of Mahaweli Development). New York.

[9] Anti-Malaria Campaign. 1978-83. *Administration Reports.* Colombo: Ministry of Health and Anti-Filariasis Campaign. 1978-78. *Administration Reports.* Mount Lavinia: Ministry of Health.

[10] Based on an Anti-malaria Campaign field staff report.

[11] Several of the suspected new malaria vectors have already developed multiple resistance to the insecticides now available (see ref. footnote 4).

concept combines chemical, biological, and environmental management methods that suit the local requirements and possibilities. In Zone 2, where the irrigation systems determines the environment in a large part of the area, the analysis and possible improvement of present water-management practicies form an essential element in environmental management for vector control.

Identifying Vector Habitats in Zone 2

Whether water forms a suitable breeding place for vectors depends on a variety of factors. In irrigated agriculture, a relationship has to be established between observed water bodies, the practices that led to their creation, and whether they will cause the proliferation of specific vectors. To establish this relationship in Zone 2, three matrices were developed:

Matrix I. Potential mosquito breeding places were classified by adapting the system described in the WHO Manual on Environmental Management for Vector Control to the local situation. The stagnant bodies of water encountered in Zone 2 were placed in one of seven categories (Table 3), according to criteria such as organic pollution, exposure to sunlight, vegetation, freshness of the water, and the size of the pool.

Table 3. Classification of the most common potential breeding places in System C, Zone 2.

A. Large bodies of fresh water in full or partial sunlight (floating or emergent vegetation occurs especially near the edges):

1. Ulhitya/Ratkinda reservoir, irrigation tanks, level crossings; large borrow pits, waterlogged pools behind filled D-channel bunds, large natural surface depressions.

2. Marshes.

B. Small water collections, stagnant and often muddy, but not polluted; full to partial sunlight:

1. Vegetation present (scattered or fringed): Marginal pockets along irrigation canals, semi permanent rain pools in natural or man-made surface depressions (e.g., in between road and canal bund), seepage pools behind tank or canal bund, old borrow pits, clogged drainage ditches.

2. Vegetation absent: Recent borrow pits, rock pools on excavation sites, new road ditches, wheel ruts, foot- or hoof-prints, rain water ground pools.

C. Marshy patches, often polluted with organic matter; abundant vegetation (oily mono-layers, iron-colored water, smell of decomposition):

1. Margins of level crossings, seepage ponds/depressions along irrigation canals constructed in fill, poorly drained, shallow but extensive surface depressions.

2. Roads saturated with water overflowing from field channels.

3. Muddy broad sections of natural drains where the water flow stagnates (mainly in upper parts of intermediate drains).

D. Paddy fields:

1. Swampy, poorly drained fallow lowland paddy fields before land preparation.

2. Recently tilled fields.

3. Fields during seeding (levelled fields, no water layer, but small shallow pools).

4. Fields during transplanting (levelled fields, shallow water).

Continued

5. Fields during crop growth.

6. Washing pits.

E. Partially or heavily shaded water under abundant vegetation:

1. Sluggish irrigation-drainage streams (slow water flow from one pool to another), pools at the interception of drains in D-channels, ponds.

2. Stagnant pools in spillway drainage beds.

F. Running watercourses, clear fresh water, direct sunlight.

1. Pools in drying stream beds (natural streams or irrigation canals), seepage pools from irrigation structures in canal beds, pools in streameroded canal depressions directly behind drop structures, turnout structures and cross regulators.

2. Irrigation ditches and lowland grass/weedy field drainage ditches.

3. Small side-pockets along shoreline of irrigation canals (erosion gullies, bund breaches, etc.).

G. Man-made containers

1. Stilling basins of irrigation structures (turnouts, cross-regulators), silt catcher of reservoir spill.

2. Wells, cisterns discarded receptacles, discarded tires, gutters, etc.

Matrix I is used with the classification list, and relates the observed breeding places to the confirmed or potential vectors responsible for transmitting diseases in Zone 2 (Fig. 3). Because data relating the mosquito species to the potential breeding places is unavailable, only the form of the matrix is shown.

Figure 3. Matrix I: Identification/relation to mosquito species.

Disease	Mosquito species	Potential breeding place A	B	C	D	E	F	G
MALARIA								
	An. culicifacies							
	An. subpictus							
	An. vagus							
	An. varuna							
	An. annularis							
	An. nigerrimus							
	An. pallidus							
	An. barbirostris							
	An. aconitus							
	An. jamesi							
	An. tesselatus							
	An. maculatus							
	An. karwari							
FILARIASIS								
	Cx. quinquefasciatus							
	Mansonia sp.							
DENGUE								
	Ae. aegypti							
	Ae. albopictus							
JAP. B. ENCEPHALITIS								
	Cx. tritaeniorhynchus							
	Cx. gelidus							

Matrix II. From direct observation of the irrigation system and of agricultural practices, and from other information, we identified (Fig. 4) the point in the irrigation system (e.g., reservoir, main canal, etc.) and in the irrigation cycle (e.g., pre-irrigation, land-preparation, etc.) where the various breeding places become an important hazard to health.

Figure 4. Matrix II: Location of potential breeding places.

	Pre-Irrigation	Land-Preparation	Crop Establishment	Vegetative Growth	Harvest	Post-Irrigation
Reservoir	A1, G1	A1, G1	A1, G1	A1, G1	A1, G1	A1, G1
Main/Branch Canal	F1	F3	F3	F3	F3	F1
Buffer Reservoirs	A2	A1;B1;C1	A1;B1;C1	A1;B1;C1	A1;B1,C1	A2
Distributary	A1;C1;G1	A1;B1,2	A1;B1,2	A1;B1,2	A1;G1;C1	A1;G1,C1
Channel	F1	F3;E1	F3;E1	F3;E1	F1	F1
Field Channel	C1;F1	B1;C1,2	B1;C1,2	B1;C1,2	C1;F1	C1;F1
Field Ditch		F2	F2	F2		
Field	D1	D2,6	D3,4,6	D5,6	D6	D1
Field Drainage		F2	B1;F2	B1;F2	B1;F2	
Natural stream	E1;F1	C3;E2	C3;E2	C3;E2	C3;E2	E1
Domestic Environ.	G2	G2	G2	G2	G2	G2
Natural Environ.	A1;B1,2 C1	AA1;B1,2 C1	A1;B1,2 C1	A1;B1,2 C1	A1;B1,2 C1	A1;B1,2 C1

Matrix II thus indicates the relative importance of the irrigation system as a whole for potential vector breeding in the area, and singles out those elements of the irrigation system that contribute most to the breeding risk.

Matrix III. Matrix III establishes the relationship between the location of the breeding places and those features of water management and irrigation engineering that cause their existence: hydrology, design, construction, etc. (Fig. 5).

Matrix III thus completes the stepwise cause-and-effect analysis, which starts with identifying the vector and ends with identifying the irrigation feature that influences vector habitat. Although the matrices still need more data from both irrigation and entomology, they provide a framework for further study of the linkage between irrigation and vector ecology under the specific environmental conditions of Zone 2.

Irrigation Features Related to Vector Habitat Creation

Matrix III directs attention to that feature of the irrigation system, which, by an analysis of its details, will prove to be the cause of a particular type of breeding place. Even so, a general rule

Figure 5. Matrix III: Relationship between breeding place and irrigation feature.

	Hydrology	Farm-Water Management	Design	Construction	Operation	Maintenance
Reservoir	A1		G1		A1	A1
Main/Branch Canal				F3		F1,3
Buffer Reservoirs	A2;C1			B1	A1	A1
Distributary	A1;B1		A1;E1	A1;B1,2;C1	C1	B1;C1;F1
Channel			G1	E1;F1,3		F3
Field Channel	A1;B1		F1	B1;C1,2;F1	B1;C1,2;F1	B1;C1
Field Ditch		F2		F2		F2
Field		D1,6				
Field Drainage	B1	F2				B1;F2
Natural stream	A1;C3;E1 E2;F1			C3;E1,2		C3;E1,2
Domestic Environ.				G2		G2
Natural Environ.	A1;B1;C1		B1	B2		B2

seems to apply: the more carefully and minutely irrigation development is planned and executed, the less likely it is to encourage mosquito propagation. Some examples of the principles under-lying this rule were observed in Zone 2.[12] *Hydrology.* The sloping and irregular topography of System C has imposed two major constraints on the drainage of the area. First, drainage of the large area of land excluded from the irrigation scheme would have required a large number of culverts and other devices because, in many cases, the newly constructed roads and canal bunds have cut off stretches of this land from the natural drains.

Second, numerous small unirrigable patches are scattered within the irrigation system's boundaries. These contain natural and man-made surface depressions that do not drain to the drainage network laid out as part of the irrigation system. These depressions collect water from blocked natural drainage, rainfall, surface runoff, and seepage, to create large and small, often brightly sunlit, bodies of stagnant water that retain an overall breeding potential for the area throughout all phases of the irrigation cycle.

Design. A complex network of reservoirs and major and minor canals resulted from the policy of creating the largest possible command area in the undulating topography and varying soil conditions of System C. The control of water flows in all parts of this network is, in itself, a complex matter, which places heavy demands on the staff operating the system. The situation is further complicated by the decision to leave canals unlined, with all the attendant problems of erosion and seepage.

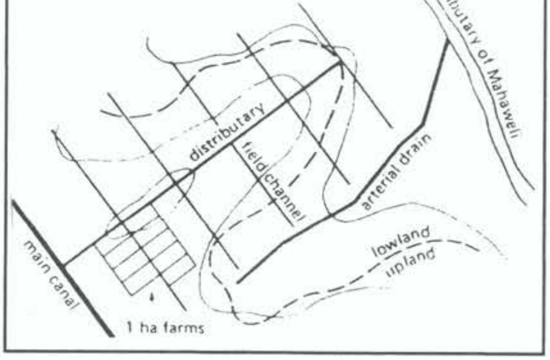
The design of separate parts of the system may create public health hazards. Figure 6 gives an example of how the canal layout has been adapted to the topography.

Distributary canals are aligned along the lateral spurs of the main ridges, which means that a major part of every distributary runs through the imperfectly to well-drained RBE soils. Where these canals have been excavated in erodible RBE soils, serious bund erosion has been observed. One effect of this erosion is the deposition of silt, which, in the pre- and post-irrigation periods, leads to uneven canal beds with many shallow sunlit pools of stagnant water. In consequence, conditions in the distributaries and branches are particularly conducive to the development of mosquito larvae until the first issue of water, after which a constant flow is maintained in the canals. Potential breeding areas remain, however, where erosion gullies in bunds form pockets of standing water.

Especially in the minor canals, there are two other effects of bund erosion: First, over the full length of the field channels and at the tail end of distributaries, the deposition of silt causes capacity problems. The subsequent overtopping of canal embankments leads to pool formation in adjoining surface depressions. Second, accelerated water flow and whirlpool action occurring downs-tream of culverts, bridges, drop and check structures, and bends, cause bank erosion. This widens the canal cross-section, retards water flow, and creates breeding places in the side pockets along the embankment. In contrast, the large Ulhitya Reservoir cannot be reckoned as a dangerous breeding place. The reservoir bund closest to the nearest settler hamlet exceeds the average flight range of most mosquito vectors: 1-3 kilometers.

Unlike Ulhitya, the score of smaller irrigation reservoirs incorporated in the system (and in proximity to human habitation) may contribute considerably to vector breeding. Often the embankments

Figure 6. Example of canal layout in System C.



[12]We should emphasize that development in the project area is still in a transitional phase. The changing environmental and other conditions may, in the long run, influence the relative importance of the observed causes of vector habitat creation.

[13]World Health Organization. 1982. *Manual on Environmental Management for Mosquito Control.* Geneva, Switzerland: WHO pub. 66. pp281.

of small irrigation reservoirs (or tanks) are infested with emergent or floating vegetation, of which *Salvinia natans* is a suspected breeding requisite for *Mansonia spp.,* thevector of Brugian filariasis.

These small reservoirs serve the purpose of buffering the effects of disproportion between frequency of adjustments in major and minor canals. Water levels, therefore, are subject to irregular fluctuations throughout the year, causing an exposed drawback zone suitable for mosquito breeding each time the water recedes. If the drawback zone does not consist of isolated small depressions, however, the shallows will empty when the water recedes, leaving the eggs, larvae, and pupae stranded.

Construction. Since 1977, the Mahaweli Development Programme has been "accelerated," which means that the tempo was increased in constructing headworks and opening new lands to irrigation. This increased tempo also meant that shortages were encountered, including: 1) Accurate topographical maps of the new lands to be developed, 2) expertise and management for planning and monitoring construction, 3) well-equipped and experienced local contractors for executing the work, and 4) supplies of high-quality construction materials.

The effects of these shortages are now appearing in the irrigation infrastructure. Examples include the following:

1. Not all the canal beds and structures have been constructed at the proper elevations. The result is incorrect water flows, stagnation of water in canal sections, and overtopping of bunds, with the consequent formation of pools in adjoining depressions.

2. Some canal sections have been constructed to fill, without being compacted, which is necessary to avoid seepage and leakage. This has led to the continuous presence of adjacent waterlogged surface depressions.

3. Complicated construction works such as large culverts, water-level regulating structures, aqueducts, and inverted syphons have not all been made with the high-quality materials they require, nor have they all been accurately installed. This is necessary not only to prevent the creation of breeding places, but also to safeguard the delivery of design water flows throughout the system.

Operation. The quality of the design and construction determines the boundary conditions within which operational procedures are laid down that supposedly guarantee a uniform and reliable supply of sufficient irrigation water. In System C, the accelerated implementation of a complex design under difficult topographical conditions has resulted in complicated operational procedures that have not been able to prevent shortages or excesses of water.

According to Moore,[14] the cause of many of the problems in large-scale irrigation schemes in Sri Lanka lies in the operational procedures applied, which rank low in formality, information, and control. His contention also holds for Zone 2.

Formality. The formality of operation in Zone 2 is characterized by: a) An almost total lack of written technical procedures for the adjustment of control gates downstream of the main canal; b) the absence of explicit job descriptions for water management staff; and c) poor coordination of policies and activities, leading to haphazard implementation of rainfall corrections, rotation schedules, cropping calendars, etc.

In circumstances like this, an alert and effective water management for the equitable distribution of irrigation water is impossible. The result is that farmers and water management staff are becoming alienated. Poaching water and damaging irrigation structures are common actions when farmers feel that their complaints about water shortages are not heard.

Information. Flow measurements are imperative if one is to verify channel flow and locate faulty design or construction in the canal system. Flows in the main and branch canals or Zone 2 are measured with Parshall flumes, and in the distributaries with short-crested (hump) weirs. Only a minimum number of measurement devices, however, have

[14]Moore, M.P. 1980. *Approaches to Improving Water Management on Large-scale Irrigation in Sri Lanka.* Colombo: Agrarian Research and Training Institute (ARTI) Occasional Pub. 20. pp47

been incorporated in the canal network, and many of them cannot be used for accurate readings because of improper elevation or the absence of a reading gauge. At present, the only records that are kept are those of the main sluice. Further down the system, unrecorded "guesstimates" from improvised methods are used for adjusting minor irrigation structures.

Control. Discrepancies between water requirements and actual amounts issued are inherent in irrigation. Some soils are more porous than others, while differences in canal topography, length, and maintenance may mean that two adjacent canals require very different - but hard to assess - amounts of water at their head ends to ensure supplies to their tail ends.

Another factor is the degree of control it is possible to exercise over the water flows. In Zone 2, from distributary level down to the fields, the vertical sluice-gate inlet structures are adjustable, but they cannot be sufficiently fine-tuned to guarantee the required flow (see footnote 2). During rainfall of more than 8 centimeters, for example, the main flow can be accurately cut back for one week to 50%. From the distributaries downward, however, the adjustments can only be approximated, which is likely to starve tail-end distributaries of water. Furthermore, rain-fall is unevenly distributed over Zone 2. Because data from only one rain gauge are used, canals at the tail ends of the system sometimes dry up.

At turnout level, farmers have difficulty controlling the water issues. During land preparation, the system operates at full capacity, delivering a continuous flow of roughly 30 liters per second to every turnout gate. But the number of farmers under one turnout varies widely, leading to over-irrigation at the smaller turnouts. This, in combination with local drainage problems, causes land to be inundated for several weeks at a time.

Along the field channels, three farmers must share the design flow by using two-outlet boxes, one of which remains half-closed. Such a discrepancy between design and rotational procedure cripples any endeavor to achieve an equitable distribution of water within the turn-out.

Too much water was issued as a palliative for these shortcomings during the wet season 1984-85, and this disguised the need for urgently required construction, reorganization, and maintenance within the system. Other risks attendant on an overgenerous supply of water are that farmers become wedded to lavish water use and lose their ability to handle water as a scarce commodity or to manage rotational water deliveries, both undoubtedly leading to the creation of vector breeding places.

Once a vector habitat has been identified somewhere in the system, it is difficult to determine whether its occurrence is related to one specific operational feature. Operational short-comings tend to have a cumulative effect. This, however, does not derogate from the general rule that the more carefully the minutely irrigation development is planned and executed, the less likely it is to cause mosquito propagation.

Maintenance. Wherever maintenance of an irrigation system is neglected, water flows will be retarded, areas will be inundated, and other processes favorable to the formation of pools of standing water are likely to take place. Maintenance work in Zone 2 is not well-organized, mainly because of the lack of consensus on responsibilities at the institutional and turnout levels.

At the institutional level, the construction of the system by one agency and the subsequent transfer of project management to another has not resulted in effective maintenance. For the first two years after construction, maintenance is the responsibility of the construction agency, but with construction still in progress in other parts of the System C, and in System B as well, this agency is having difficulty in releasing the manpower and machinery needed for maintenance in Zone 2.

At turnout level, the operation and maintenance of the infrastructure is left to the farmers. They elect a farmer-leader to represent them and to see that works are executed according to agreed-upon procedures. The farmer-leader, however, lacks the authority to enforce the rule that every farmer must clean the canal section adjoining his or her paddy plot, so not all farmers do their share of the work. The result is excessive plant growth in the canals, damaged canal bunds, and silted canal beds.

Another factor complicating cooperation at the turnout is hidden tenancy, which makes the ownership of some plots unclear.[15]

On-farm Water Management and Crop Husbandry. Two methods of rice cultivation are practiced in Zone 2. One is the "transplanting" method, which uses plant material from a nursery; the other is "direct seeding," by which seeds is broadcast directly on the fields and no transplanting is done.

Farmer's activities in irrigated rice cultivation and the implication of these activities on vector breeding have been extensively studied by the Food and Agriculture Organization (FAO).[16] One important feature appears to be underestimated, however, namely that a farmer's decisions on the sequence of his activities and the techniques he applies to his cultivation and irrigation practices are not taken autonomously. To a large extent, these decisions are constrained by the timely and adequate availability of the necessary inputs: water, labor, traction power, seed, and fertilizer. Thus, basic input provisions must be safeguarded before the farmers can employ cultivation techniques that will minimize the creation of vector breeding places.

Broadcasted paddy fields appear to provide more breeding grounds than transplanted fields because of the absence of a uniform water layer in the first two weeks after seeding and a relatively slow closing of the crop canopy. Nevertheless, a potentially dangerous situation occurs with a transplanted rice crop when a second nursery proves necessary because the first did not provide enough plant material for the full one hectare plot. This leads to an extra three weeks of fallow for the still unplanted but tilled fields.

During our field observations, we found that each cultivation stage maintained its typical breeding habitats. In the pre-cultivation period, often waterlogged, poorly drained, lowland fallow fields are favorable for mosquito breeding. In the land preparation period, the recently plowed fields form a vast inundated area in which the chances for breeding depend (among other things) on the interval between successive activities. A rule of thumb is that a plowed basin left untouched for ten days or longer (in the climatic circumstances of Zone 2) allows a high percentage of the larvae enough time to develop into adult mosquitoes.

During crop and canopy establishment, the breeding danger is thought to lessen because the vegetative cover hinders the oviposition of female anopheline mosquitoes (see footnote 16). But other water bodies remain: borrow pits, undrained depressions along irrigation canals, seepage ponds, blocked drains. In the wet season of 1984/85, this situation was aggravated by the continuous oversupplies of irrigation water.

After the harvest, when the sluice gates have been closed, the enormous lengths of drying-up canals are particularly attractive for the proliferation of mosquitoes, and the marshy fallow fields constitute a favorable breeding habitat for *Culex tritaeniorhynchus,* especially after the first rains have fallen on the decomposing stubble (see footnote 13).

Conclusion

Despite the complexity of relationships between irrigation engineering and the creation of vector breeding places, efficient water management can impede the creation of the latter. It remains to be seen, however, whether a reduction in the breeding potential in Zone 2 will find expression in an actual reduced density of the vector populations. The large area that could not be incorporated into the irrigation system offers alternative breeding grounds that will certainly diminish the effectiveness of any environmental management measures incorporated into the engineering works.

Still, an overall improvement in water management should be an important component in any irrigation project - serving, as it does, the dual purpose of better control over vector breeding and an increased agricultural productivity. Once water management has been improved, thought can be

[15] Gunawardena, L. 1983. Analysis of Zone 2, System C. Colombo: Mahaweli Economic Agency.

[16] Mather, T.H. and Trink Than That. 1984. *Environmental Management for Vector Control in Rice Fields.* Rome, Italy: FAO Irrigation and Drainage Paper 41.

given to more complex environmental management measures for vector control. Given the present technical and organizational level of water management in Zone 2, however, such measures are not yet relevant.

In Sri Lanka, it is now increasingly being recognized that the medical profession cannot be held solely responsible for remedial action against the health risks introduced by engineers. What is needed for the long-term control of vector-borne diseases is inter-sectoral collaboration between the engineering and the medical professions - at ministerial level and at project level. This is a prerequisite to the incorporation of preventive measures in the design and management of irrigation projects.

In the process of establishing integrated control of disease vectors in Zone 2 - and in other parts of the Mahaweli Project - irrigation water management would be a good place to start.

Irrigation Management and Human Health: A Perspective from IIMI

Leslie Small[1]

Introduction

Water is a critical resource affecting the fundamental welfare of primary producers throughout today's world. Especially in less-developed countries (LDCs) human well-being and productivity are directly affected by the nature, source, and use of water supplies for agricultural production, household consumption, and disposal of wastes. In areas served by irrigation facilities, the nature of the irrigation system and its management may affect not only the agricultural productivity of rural people, but also their general health. Health consequences of irrigation derive from the effects of changes in the environment on the prevalence of water-related diseases such as malaria.

Irrigation and Agricultural Production

The need for increased agricultural production is critical in many LDCs because of their population and income growth which creates a rapidly rising demand for food. For an increasingly large number of LDCs, reliance on the expansion of cultivated area to meet increased food demands is no longer economically attractive. Attention has shifted to methods of increasing the intensity with which existing agricultural land is used. This involves the development of biological and chemical technology that can increase the yield per unit of cultivated area. Efforts in this direction have met with considerable success, particularly with rice and wheat.

The full potential of the new technology can be realized only if water is carefully controlled. As biological developments permit an increasing number of crops to be grown per year on a given piece of land, irrigation often becomes the primary production constraint. The new technology has thus greatly expanded the potential economic return from irrigation development and improvement. Irrigation is frequently considered to be the key link in the chain of technical developments leading to increased production.[2]

These conditions have resulted in substantial investments in new and improved irrigation facilities, particularly in Asia where this trend is likely to continue for the remainder of the century. Irrigation investment estimates to meet food production targets for a 15-20 year period in Asian nations range from US$42-53 billion expressed in 1975 dollars.[3]

[1] Agricultural Economist, International Irrigation Management Institute, Digana Village via Kandy, Sri lanka.

[2] Asian Development Bank. 1978. Rural Asia: Challenge and opportunity in *Second Asian Agriculture Survey*, Vol.1. manila, Philippines. p127. Herdt, R.W. 1980. Studies in water management economics at IRRI, in *Report of a Planning Workshop on Irrigation Management*. Los Banos, Philippines: International Rice Research Institute (IRRI). pp115-138.
Herdt, R.W. and T.H. Wickham. 1978. Exploring the gap between potential and actual rice yields: The Philippine case, in *Economic Consequences of the New Rice Technology*. Los Banos, Philippines: IRRI. pp3-24. International Rice Research Institute. 1980 *Report of a Planning Workshop on Irrigation Water Management*. Los Banos, Philippines.

[3] Colombo, U., D. G. Johnson, and T. Shishido. 1978. *Reducing Malnutrition in Developing Countries: Increasing rice production in South and Southeast Asia*. Report of the Trilateral North-South Food Task Force to the Trilateral Commission, Triangle Paper No. 16, June. Food and Agriculture Organization of the United Nations. 1980. *Agriculture Toward 2000: Regional implications with special reference to the third development decade*. Prepared for the 15th FAO Regional Conference for Asia and the Pacific, New Delhi, March 5-13. Oram, P., J. Zapata, G. Alibaruho, and S. Roy. 1979. *Investment and input requirements for accelerating food production in low income countries by 1990*. Washington, DC: International Food Policy Research Institute (IFPRI) Research Report No. 10.

The enthusiasm for irrigation as a key to increased food production has frequently not been matched by results. Numerous problems have lowered returns considerably below original expectations. It is now widely recognized that constructing dams and canals will not automatically lead to substantial increases in production. Attention has shifted toward an examination of problems in the operation and management of irrigation systems, and the types of investments needed to improve the management of these systems.[4]

IIMI'S Research Program

Within this context the International Irrigation Management Institute (IIMI) was created. IIMI began operations in mid-1984 as an international organization whose primary purpose is to undertake research, professional development, and information exchange activities to enhance national capacities to improve the management and performance of irrigation systems.

IIMI, as a small, decentralized institute, must develop a research program that is clearly focused on broad problems of practical importance, both to those who manage irrigation projects and to those who make policies affecting the conditions in which the irrigation systems are planned, financed and operated. The research should not be limited to investigations of specific problems faced by a national irrigation agency but focus on problems with international application. The former problems are better addressed by national research programs.

During IIMI's first year, considerable effort was devoted to the delineation of an appropriate research program. These efforts included two international workshops held during 1985. From these deliberations came a framework which incorporates three general areas of investigation: main system management, rehabilitation and design for management, and small-scale irrigation.

Research on system management will include studies on the operation of irrigation systems from the main head gates and canals to the individual farm fields. The program on rehabilitation and design for management looks at ways to more effectively upgrade both the physical and organizational components of deteriorated irrigation systems. Emphasis is placed on incorporating the knowledge and experience gained from past operation of the system. Research on small-scale irrigation systems will investigate the performance of systems operated in the absence of significant governmental involvement. A major objective is to understand factors critical to the successful operation of such autonomous systems, and to study the implications of proposed government interventions to upgrade them.

There are several dimensions to irrigation management, all of which need to be considered in undertaking research. As indicated in Figure 1, these dimensions apply to each of the three research program areas. In each, IIMI will be concerned with understanding the institutional and social dimension (the behavior of people, including government agency personnel, water users, and external consultants); the physical dimension (the movement, storage, upkeep, and utilization of materials and structures); the biological dimension (the manipulation of the biological environment); the information dimension (the acquisition, processing, and dissemination of information); and the financial dimension (the acquisition, control, and utilization of financial resources).

IIMI and Research on Health Implications of Irrigation Management

The relationships between irrigation and human disease vector populations fall under the biological dimension of irrigation management, an area of interest to IIMI. The objective of this workshop is

[4]Botrall, A.F. 1981. *Comparative Study of the Management Organization of Irrigation Projects.* Washington, DC: World Bank Staff Working Paper No. 458. May. Taylor, D.C. and T.H. Wickham (eds.). 1979. *Irrigation Policy and the Management of Irrigation Systems in Southeast Asia.* Bangkok, Thailand: The Agricultural Development Council. Svendsen, M., D. Merrey, and W. Fitzgerald. 1983. Meeting the challenge for better irrigation management, *Horizons* 2(3):17-25.

Figure 1. Management dimensions of IIMI's research program areas.

Dimensions	Research Program Areas		
	Main System Management	Rehabilitation Design for mgmt	Small-scale Systems Mgmt
Institution & Social	X	X	X
Physical	X	X	X
Biological	X	X	X
Informational	X	X	X
Financial	X	X	X

to determine how the problems of vector control can be addressed through changes in irrigation management.

At least five approaches to dealing with vector-borne disease problems can be identified. One approach is that of environmental management, which has been discussed in a recent FAO publication[5] and by Dr. Shisler's workshop paper (in this volume). A second approach is to attack the problems through irrigation design. Canal lining, design of canals for relatively high velocities of water flow, and provision of deep drains with steep slopes are among the possibilities that have been suggested.[6] A third approach is the use of chemicals to reduce vector populations. Fourth, vector populations may be reduced through biological control methods, such as the introduction of competitors, predators and infectious agents. Finally, a medical approach focuses on methods of immunizing or otherwise reducing the susceptibility of the human population to the diseases transmitted by the vectors.

Although the above five approaches to control of vector-borne diseases are frequently complementary, the critical questions which IIMI must consider with respect to any particular disease problem are: 1) to what extent is the environmental management approach likely to be a cost-effective method of control; 2) assuming a positive conclusion to the first question, to what extent can the changes in environmental conditions induced by irrigation management techniques be expected to have a significant effect on the disease problem; and, 3) assuming a positive conclusion to the second question, are there significant research questions regarding alternative management techniques which need to be considered, or is the problem simply one of implementing techniques which have already been proven?

In considering the second question, a distinction should be made between irrigation in semi-humid areas where the predominant crop is rice and irrigation in more arid areas where crops other than rice predominate. In the former case, which is typical of Sri Lanka, parts of India, and most of Southeast and East Asia, the nature of agricultural production dictates high groundwater tables and widespread areas of standing water. Under these conditions one needs to question the feasibility and/or the effectiveness of some of the management techniques suggested to control vector populations. Among these are changes in the water level of reservoirs, rotational irrigation, and alternate wetting and drying of irrigation channels. It has been noted in the Mahaweli Project that even when irrigation channels are closed between the two cropping seasons, erosion in the channel beds results in stagnant pools of water in the canals. Perhaps in such a water-dominated environment, effective control of vector populations can be achieved only as a result of a

[5]Mather, T.H. 1984. *Environmental Management for Vector Control in Rice Fields.* Rome, Italy: FAO Irrigation and Drainage Paper No. 41.

[6]Kay, M.G. and R.C. Carter. 1984. Health hazards in irrigation development: A strategy for improvement, *Outlook on Agriculture* 13(3):125-129.

[7]Jayaraman, T.K. 1982. Malarial impact of surface irrigation projects: A case study from Gujarat, India. *Agriculture and Environment* 7:23-34.

[8]Jayawardene, J. 1985. Water management practices in Mahaweli Development areas, in *Intersectoral Collaboration for Malaria Control in Sri Lanka.* Colombo, Sri Lanka: Ministry of Health/Anti-Malaria Campaign, Report of a seminar, April 22-26. pp53-57.

broad-based environmental management program, of which irrigation management is a minor component. The situation may be quite different in areas where water is less abundant and crops are grown under non-flooded conditions.

As IIMI defines its research program and priorities, answers to the three questions posed above will be very important. A workshop to identify IIMI research priorities concluded that a number of important areas of investigation significantly related to irrigation performance, such as watershed management, should not be part of IIMI's research program.[9] To be effective, IIMI needs to have a research program which focuses clearly on irrigation management.

The fundamental question is whether the prospect for improvement in human health resulting from research on vector control through irrigation management justifies a major research effort by IIMI. If the conclusion is "yes," then we seek guidance on the types of research activities that would seem most promising; if the consensus is "no," the workshop will have been valuable in helping to clarify IIMI's research priorities.

[9]Small, L.E. 1985. *Research Priorities for Irrigation Management in Asia.*" Digana, Sri Lanka: IIMI Research Paper No. 1.

The Relationship Between PEEM and IIMI

David J. Bradley[1]

It would be an unfortunate perpetuation of a long-standing pattern if the relationship between irrigation and health continues to be ignored. Figure 1 shows the stated involvement of IIMI in the most important aspects of irrigation. Its emphasis is on the human, institutional, operational, and maintenance phases of irrigation. It is concerned also with performance, evaluation, and rehabilitation of irrigation schemes, and with the physical and biological components of irrigation methodology at the farm level. These activities must be analyzed in relation to the epidemiological issues which arise in health matters, and a coordinated approach which is appropriate for IIMI's situation and resources must be formulated.

What aspects of health are relevant? There is a temptation to suggest that the concern should be limited to the control of vectors because this is the immediate point at which irrigation water is of particular importance to infectious disease. However, Figure 1 illustrates that such a narrow focus is not sound. It shows the incidence of malaria in relation to the basic case reproduction rate, with emphasis on the situation in the African savannah and in Sri Lanka. A proportionate reduction in the same level of vector breeding in each country will have a totally different effect on malaria incidence. A twenty-fold reduction in the vector density might greatly reduce or even eradicate malaria in parts of Sri Lanka, whereas a corresponding reduction of mosquitoes in the African savannah would have a negligible effect on the occurrence of human malaria. Since our concern is primarily with the diseases mosquitoes carry, it is clear that an epidemiological component, in addition to a vector component, is necessary for a rational policy at IIMI.

IIMI's selection of priorities will fill some of the large gaps in our understanding of irrigation. Numerous studies of large dams have contributed to our understanding of what needs to be done, relative to health, when such dams are built in tropical countries. However, there have been very few studies of small dams. Problems of small dams are often more severe because small works are not financed by external borrowing and, therefore, control over what happens is limited and funds for the correction of mistakes are scarce. Small dams are being constructed at a great rate in many parts of the world, such as in Nigeria which has some 300 small dams completed or under construction. Yet studies of small dams can be of great value. For example, if the correct way to minimize disease can be determined from a study of 10 small dams in Nigeria, there are 30 times more dams where this information can be applied.

Irrigation schemes have been studied less than dams, although there have been rather comprehensive studies of a number of large irrigation schemes, most notably that in the Gezira area of the Sudan,

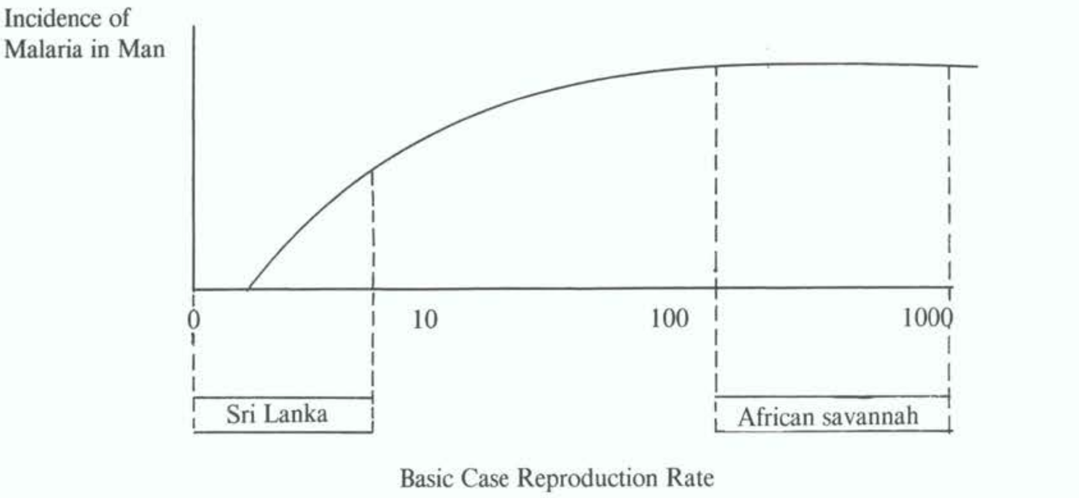
Figure 1. Areas of concern to IIMI in relation to work of PEEM.

	Planning & Design	Construction	Operation & Management	Irrigated Farming	Performance Evaluation	Rehabilitation
Physical		+	*	*		+
Biological			*	*		
Human & Inst	*	*	*	+	*	*
Information	+	+	*	+	*	*
Financial		+	*	+		+

+ important; * important and of interest to IIMI.

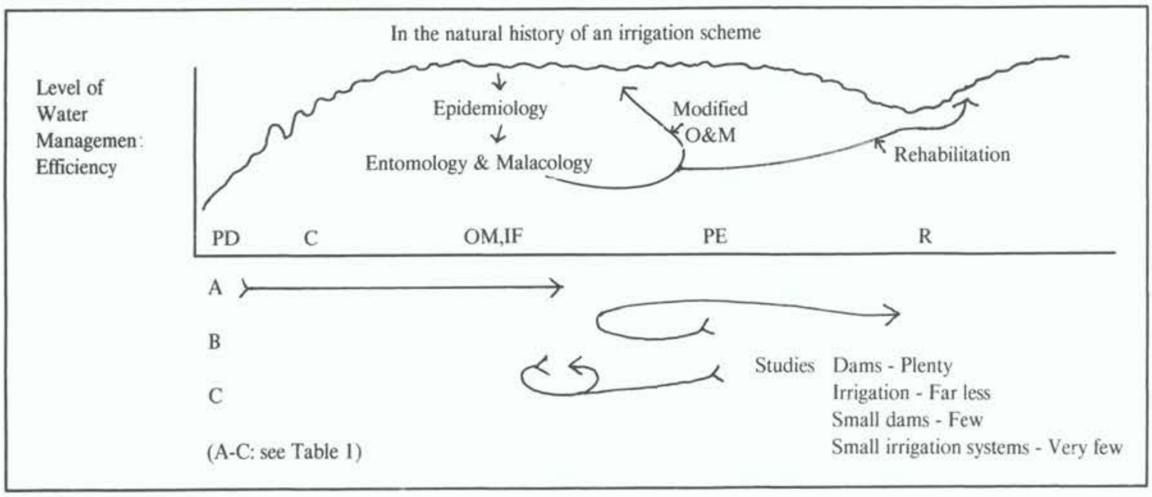
[1]London School of Hygiene and Tropical Medicine, United Kingdom.

Figure 2. The effect on the incidence of disease in different habitats by a tenfold reduction in vector density.



which has a population in excess of 2 million. Less work has been done on small irrigation schemes, yet the populations involved are considerable, and the possibilities for improving health are great. Entomological and malacological studies of dams and irrigation schemes are numerous relative to epidemiological studies. Interventions to improve health have been focused on one or, at the most, two specific diseases rather than on the overall health needs of the populations involved. There is clearly a great need for better advice at the planning and construction stage. There are a limited number of longitudinal observations made between the pre-construction stage and the time when the irrigation scheme becomes operational, and it has become clear that conclusions based on short term observations can be quite misleading because it takes a long time for a large dam to settle down after its construction. The overall conclusion is that there is a special need for epidemiologically-based health studies of irrigation schemes, particularly small irrigation schemes, and that these will more likely effect improvement if they are done prior to rehabilitation. This is summarized in Figure 3.

Figure 3. Health and environmental management of vectors.



We conclude, therefore, that irrigation schemes in a steady state should be studied from an epidemiological point of view in order to determine the major health hazards. This should lead to specific entomological and malacological studies which will be the basis for the modification of operation and maintenance procedures which will contribute to improved health. Such studies can be utilized even more effectively when irrigation schemes are to be rehabilitated.

The recommended sequence of research activities to achieve improvement in vector-caused health problems should:

1. Assess epidemiology.

   a. Use available data.
   b. conduct specific surveys (also use as baseline for interventions).

      1) cross-sectional.
      2) longitudinal over a year.
      3) Simple surveillance systems.

2. Evaluate priorities.

3. Identify vector processes (biological and engineer-ing field work).

4. Propose irrigation management/environmental management interventions.

5. Estimate feasibility and cost effectiveness (aim to achieve transition from welfare to investment).

6. Conduct pilot scale trial (include assessment, and repeat early surveys).

7. Introduce control measures.

IIMI should be concerned with stages 2 and 4-7, with an emphasis on conducting certain studies in selected irrigation schemes with a view to developing a methodology, while PEEM should focus on stage 1 (epidemiology) and stage 3 (vectors).

Stage 1 is an epidemiological assessment to determine the changes which are most needed. This can be derived from available data and conducting specific surveys. These surveys will involve the study of a defined population over a one-year period and also provide baseline data for a pilot or larger scale trial. It will be essential also to design simple, low-cost health surveillance systems which will provide on-going information about health issues. These epidemiological assessments will assist in the establishment of priorities (stage 2). Where the diseases concerned are relevant to PEEM, an analysis should be made of the ecological processes affecting the vectors and how they may be modified (stage 3). This will require biological and engineering field studies and will lead to proposals for interventions (stage 4) in which environmental management (of particular concern to PEEM) will link closely with irrigation management (of particular concern to IIMI). Once limited types of intervention are selected, it will be necessary to determine feasibility and to estimate the cost effectiveness of such interventions (stage 5). It will be particularly important to introduce interventions which will not be viewed merely as welfare, but which will actually result in investment leading to greater productivity. This involves not only an assessment of the effect of the health of the inhabitants upon the operation of the irrigation scheme, but also the selection of interventions which will reduce vector populations and increase agricultural productivity. It has been shown that combining these two goals is highly satisfactory. The interventions selected should be tested by a small pilot-scale trial and assessed against the earlier baseline observations (stage 6). If the intervention is successful, the inputs needed to achieve general introduction of these measures must be determined (stage 7).

This summarizes what needs to be done. It is clear that IIMI will want to be closely involved, but may -and indeed usually will - find that collaboration with other institutions will be the most efficient and effective way to achieve the necessary changes. IIMI's specific involvement in relation to particular irrigation programs can include:

1. Obtaining health assessment when closely involved with an irrigation system.

2. Determining key relevant health problems.

3. Analyzing possibility of vector change by environmental management.

4. Determining relation of the above to operation and maintenance of system and to irrigation management.

The first priority when IIMI becomes involved in the study of a particular irrigation system will be an assessment of the health issues. This may be done by utilizing neighboring health organizations as consultants rather than expanding the staff of IIMI. IIMI and the contracting organization will select and focus action on key health problems of the scheme.

The health assessment must be followed by an analysis to determine if changes in vectors can be achieved by environmental management and also to assess other ways in which the diseases concerned may be changed. If the opportunity exists for environmental management of vectors, or the reduction of vector-person contact through changes in people's behavior, IIMI will become more directly involved by relating the proposed interventions to the operation and management of the system and to irrigation management generally. The final stage will be an experimental trial of the proposed control methods. In this way IIMI can make an accurate assessment of the health aspects of irrigation management without allocating too large a part of its resources to health matters.

To summarize, irrigation management and related methodologies must be developed which will contribute to the improvement of health of those who work on or live near irrigation schemes. This may be achieved in three ways: 1) improvements in the design and construction of irrigation schemes, 2) studies of the operation of irrigation schemes with a view to their improvement, and 3) a health-oriented study of decrepit irrigation schemes so that health and agricultural production may be improved.

IIMI needs to ensure that whenever they become heavily involved with a particular irrigation scheme, the health issues are brought in at an epidemiological level. They should aim to solve the problems of that particular site, and to produce a methodology that will be applicable elsewhere. They should utilize nearby health organizations to assist in assessing the problems and the formulation of interventions, which will then be integrated by IIMI into a practical rehabilitation or improved operation and maintenance program. In this way the goals of PEEM and IIMI can be coordinated into an effective policy.

Workshop on Irrigation and Vector-Borne Disease Transmission

Tuesday, 15 October 1985

08:15 Welcome and Introductions
Dr. Thomas Wickham, Director General, International Irrigation Management Institute (IIMI)

08:30 Session 1: Effects of Irrigation on Malaria in Sri Lanka
Chairperson: Mr. Joe Alwis, Ministry of Lands & Land Development

The Present Malaria Situation in Sri Lanka with Particular Reference to Areas where Irrigation has Recently been Introduced
Dr. M. U. L. P. Samarasinghe, Acting Director, Anti-Malaria Campaign

09:45 Session 2: Current Studies on Vector Population
Chairperson: Dr. D. J. Bradley, PEEM

Current Studies on Vector Populations in Areas under Development in Mahaweli System C
Dr. F. P. Amarasinghe, University of Peradeniya

Study of Mosquito-Borne Diseases in some New Irrigation Schemes in Sri Lanka, with Particular Reference to Filariasis and Abroviral Diseases
Dr. U. T. Vitarana, Director, Medical Research Institute

Study of Vector Aspects of Mosquito-borne Diseases in some Irrigation Schemes in Sri Lanka
Dr. P. R. J. Herath, Senior Entomologist, Anti-Malaria Campaign

13:30 Session 3: Irrigated Agriculture and Vectors
Chairperson: Mr. D. J. Bandaragoda, Mahaweli Economic Agency

Irrigation and Vector-borne Diseases: A Case Study in Sri Lanka
Mr. J. de Wolf, International Institute for Land Reclamation and Improvement (ILRI), Netherlands

15:30 Session 4: Managing Irrigation for Vector Control
Chairperson: Dr. Chris Panabokke, International Irrigation Management Institute (IIMI)

Environmental and Water Management for Vector Control
Dr. J. Shishler, Rutgers University

Irrigation Management and Human Health: A Perspective from IIMI
Dr. Leslie Small, Agricultural Economist, International Irrigation Management Institute (IIMI)

Wednesday, 16 October 1985

08:30 Session 5: Priorities for Future Activities
Chairperson: Dr. U. T. Vitarana, Medical Research Institute

Institutional Arrangements between the Health and Irrigation Sectors: Present Status and Suggestions for Improvement
Mr. D. J. Bandaragoda, Executive Director, Mahaweli Economic Agency

Research Priorities in the field of Water Management and Vector Control
Dr. Robert Bos, Associate Scientist, World Health Organization

Workshop on Irrigation and Vector-Borne Disease Transmission

LIST OF PARTICIPANTS

Dr. F. P. Amarasinghe
Senior Lecturer
Department of Zoology
University of Peradeniya, Peradeniya
Sri Lanka

Mr. D. J. Bandaragoda
Executive Director
Mahaweli Economic Agency
T B Jaya Mawatha, Colombo 10
Sri Lanka

Dr. Y. H. Bang
Regional Entomologist
WHO Regional Office for South East Asia
World Health House, New Delhi
India

Dr. V. K. Barbiero
Public Health Adviser
USAID, S6T/H/CD
Washington, DC 20523
USA

Mr. D. Berthery
Agricultural Engineer
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Dr. R. Bos
Scientist
World Health Organization
Division of Vector Biology and Control
Geneva
Switzerland

Dr. D. J. Bradley
Director, Ross Institute
Chairman, Division of Tropical and Communicable Diseases
London School of Hygiene & Tropical Medicine
Keppel Street, London WC1E 7HT
United Kingdom

Mr. J. de Wolf
International Institute for Land Reclamation and Improvement (ILRI)
PO Box 45, 6700 AA Wageningen
The Netherlands

Mr. P. N. D. Abeygunawardene
Consultant
South Asia Cooperative Environment Programme
Amarasekera Mawatha, Colombo 5
Sri Lanka

Dr. D. Groenfeldt
Anthropologist
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Mrs. V. Gunatilake
Entomologist
South Asia Cooperative Environment Programme
5 Amarasekera Mawatha, Colombo 5
Sri Lanka

Prof. Chamlong Harinasuta
Coordinator
SEAMO TROPMED Project
Bangkok
Thailand

Dr. Pushpa Herath
Senior Entomologist
Anti-Malaria Campaign
PO Box 1472, Narahenpita, Colombo 5
Sri Lanka

Mr. M. B. Jansen
Environmental Officer
Mahaweli Economic Agency
493 TB Jaya Mawatha, Colombo 10
Sri Lanka

Mrs. N. Jayasekera
Entomologist
Medical Research Institute (MRI)
Baseline Road, Colombo 8
Sri Lanka

Mr. J. A. J. Jayasuriya
Senior Deputy Director
Dept of Irrigation, Colombo
Sri Lanka

Ms. Ruvani Jayawardene
Ph.D. candidate (Medical Anthropology)
University of Connecticut
1 Flower Ave, Colombo 7
Sri Lanka

Dr. K. S. P. Kalpage
Entomologist
Anti-Filariasis Campaign
28 Hotel Road, Mt. Lavinia
Sri Lanka

Dr. B. J. Kay
Head
Vector Biology and Control Unit
Queensland Institute of Medical Research
Bramston Terrace, Herston, Brisbane Q 4006
Australia

Prof. Lu Bao Lin
Director
Dept of Vector Biology and Control
Institute of Microbiology & Epidemiology
PO Box 130, Beijing 100800
People's Republic of China

Dr. Ed Martin
Agricultural Economist
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Dr. Senen Miranda
Senior Scientist-Engineer
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Dr. Poh Kok Ng
Post-doctoral Fellow
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Ms. Eilene Oldwine
Chief
Health, Population and Human Resources, USAID
44 Galle Road, Colombo 3
Sri Lanka

Dr. J. M. V. Oomen
International Institute of Land Reclamation and Improvement (ILRI)
PO Box 45, 6700 AA Wageningen
The Netherlands

Dr. C. R. Panabokke
Agricultural Scientist
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Dr. J. S. M. Peris
Senior Lecturer
Dept of Microbiology, Faculty of Medicine,
University of Peradeniya
Sri Lanka

Dr. P. S. Rao
Systems Scientist
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Dr. L. Samarasinghe
Acting Director
Anti-Malaria Campaign
PO Box 1472, Colombo 5
Sri Lanka

Dr. Ranil Senanayake
Director
Institute of Sustainability
Colombo
Sri Lanka

Dr. J. Shisler
Entomologist
Mosquito Research Control
Rutgers University
New Brunswick, NJ 08903
USA

Dr. Leslie Small
Agricultural Economist
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Dr. Santasiri Sormani
Dean
Faculty of Tropical Medicine, Mahidol University
460/20, Rajvithi Road, Bangkok 10400
Thailand

Mr. John Styvers
Entomologist/Vector Control Specialist
International Science & Technology Institute
Colombo
Sri Lanka

Dr. U. T. Vitarana
Director
Medical Research Institute
Baseline Road, Colombo 8
Sri Lanka

Dr. T. Wickham
Director General
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

Dr. F. A. Wickremasinghe
Project Coordinator
International Science & Technology Institute
c/o Anti-Malaria Campaign
PO Box 1472, Narahenpita, Colombo 5
Sri Lanka

Dr. M. B. Wickremasinghe
Entomologist
Anti-Malaria Campaign
PO Box 1472, Narahenpita, Colombo 5
Sri Lanka

Dr. M. de S. Wijesundera
Head
Dept of Parasitology, Faculty of Medicine
University of Peradeniya
Sri Lanka

Dr. R. Zeledon
Consejo Nacional De Investigaciones Cientificas
y Technologicas
PO Box 10318, San Jose
Costa Rica